

1st Part

Single-Spin Asymmetries in High Energy Proton+Proton and Lepton+Nucleon Collisions

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Dec. 23th and 25th, 2013. Discussions@PKU

Thank you very much Bo-Qiang,
Yajun, Prof. Chao, Shi-Lin ...
and many other colleagues from PKU:

Xin Qian

Feng Yuan

Hongxue Yie

Ran Han

Bowen Xiao

Zhengyun You

Kun Liu

Zhun Lu

Haiwang Yu

Jiacai Zhu

Xiao-Rui Lu

(Hai-Jiang Lu)

...

Outline for Today

I will discuss experimental results, physics impacts, interpretations, and the connections of the observed single spin asymmetry (SSA) phenomena in:

- **Inclusive hadron SSA observed in proton-proton collision at Fermilab and RHIC.**
- Target SSA in semi-inclusive deep inelastic scattering (SIDIS).
- New Jefferson Lab results of polarized target SSA in inclusive hadron production $e+N \rightarrow h+X$.

I will also discuss on-going and future experimental efforts, including :

- **Polarized target Drell-Yan experiments at Fermilab (E-1039).**
- Forward jet production asymmetry in $p+p$ with the upgraded PHENIX experiment at RHIC.

I will raise my own questions to PKU colleagues during the seminar for discussions.

Outline for Wednesday

I will discuss experimental results, physics impacts, interpretations, and the connections of the observed single spin asymmetry (SSA) phenomena in:

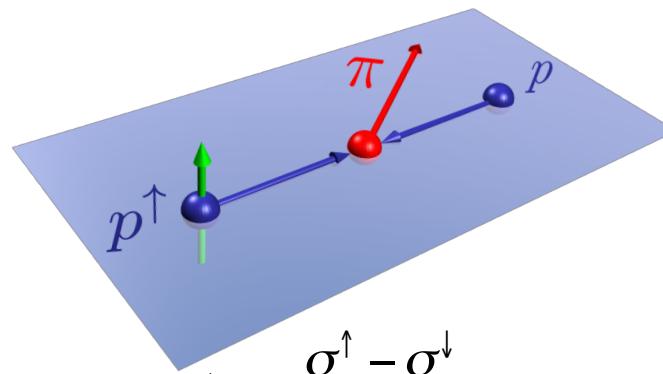
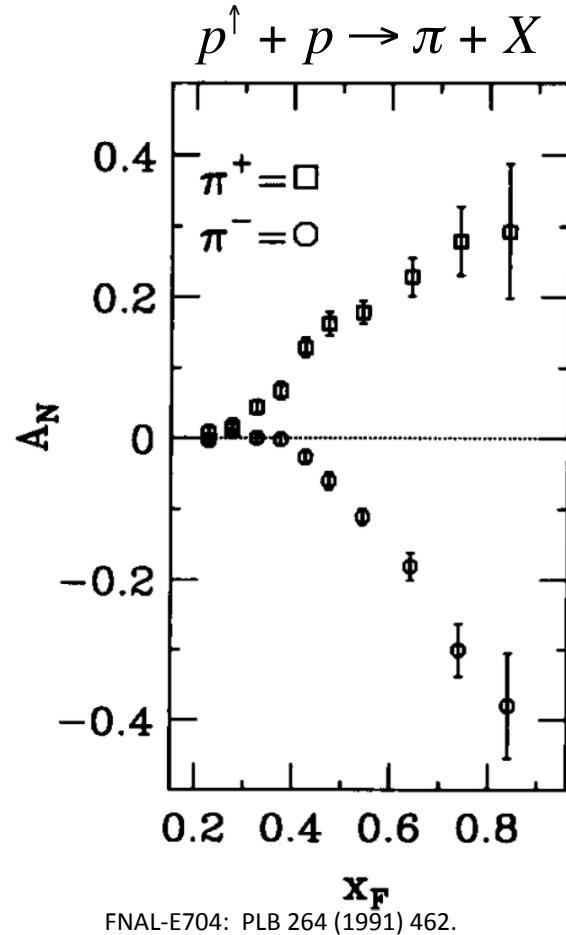
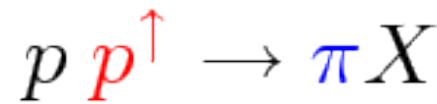
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Quarks can tell left-right in

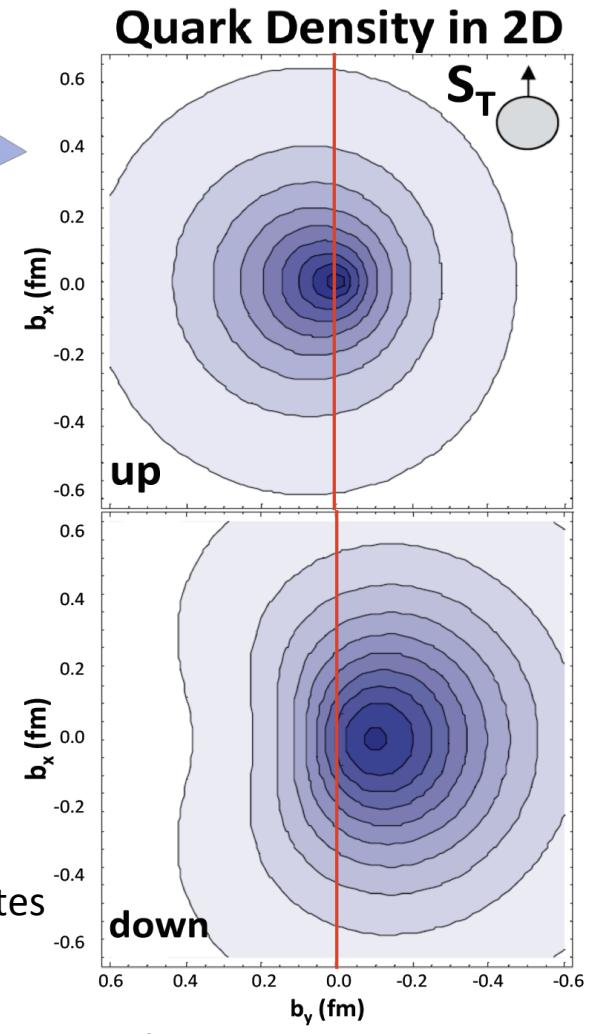


$$A_N = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow}$$

π^+ ($u\bar{d}$) favors left

π^- ($d\bar{u}$) favors right

One explanation (Sivers effect):
quark's transverse motion generates
a left-right bias.



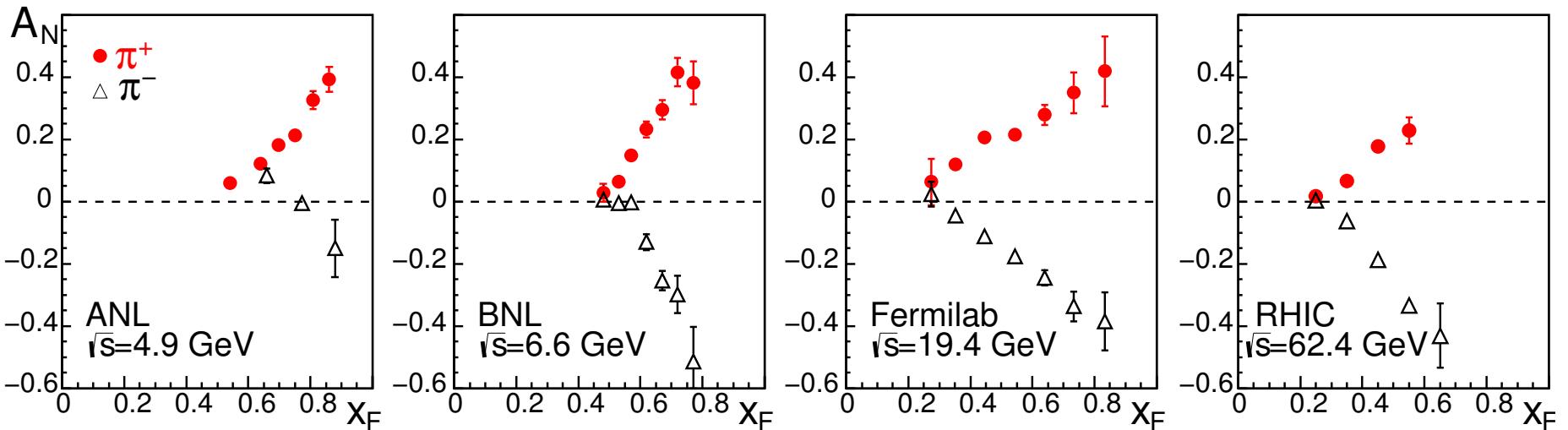
up-quarks favor left ($L_u > 0$), down-quarks favor right ($L_d < 0$).

Viewing along the polarized proton's momentum direction,

π^+ ($u\bar{d}$) favors the left-side, π^- ($d\bar{u}$) favors the right side of the proton spin vector.

Inclusive Hadron Single Spin Asymmetries in p+p

Large, forward A_N in hadron production in p+p have been measured since the mid 70's



Viewing along the polarized proton's momentum direction,

π^+ ($u\bar{d}$) favors the left-side, π^- ($d\bar{u}$) favors the right side of the proton spin vector.

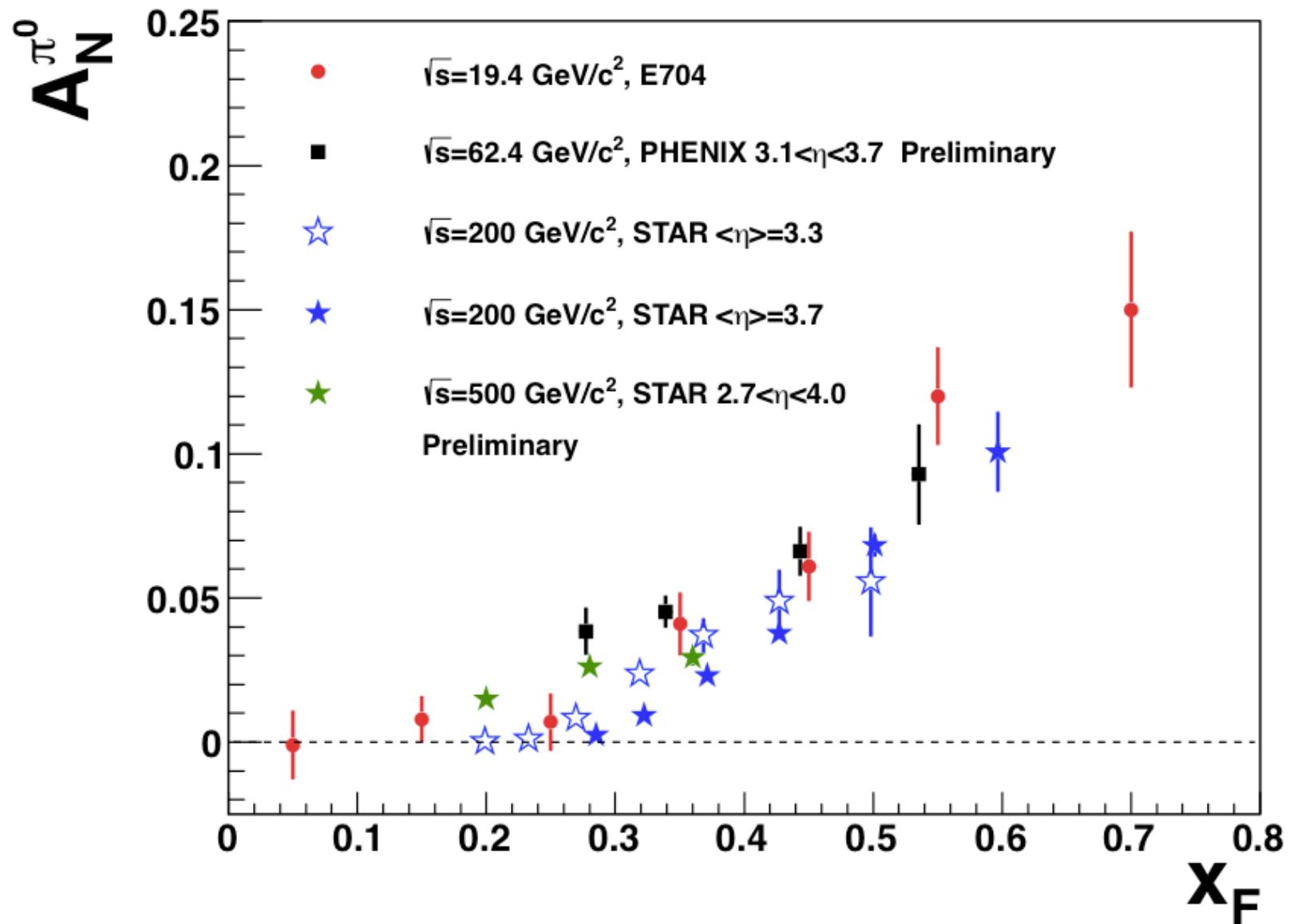
The asymmetries persist from low CM energies to high CM energies.

$$x_F = \frac{2p_L}{\sqrt{s}}$$

A simple (collinear) pQCD calculation tells us that an A_N can exist, but that it should scale like

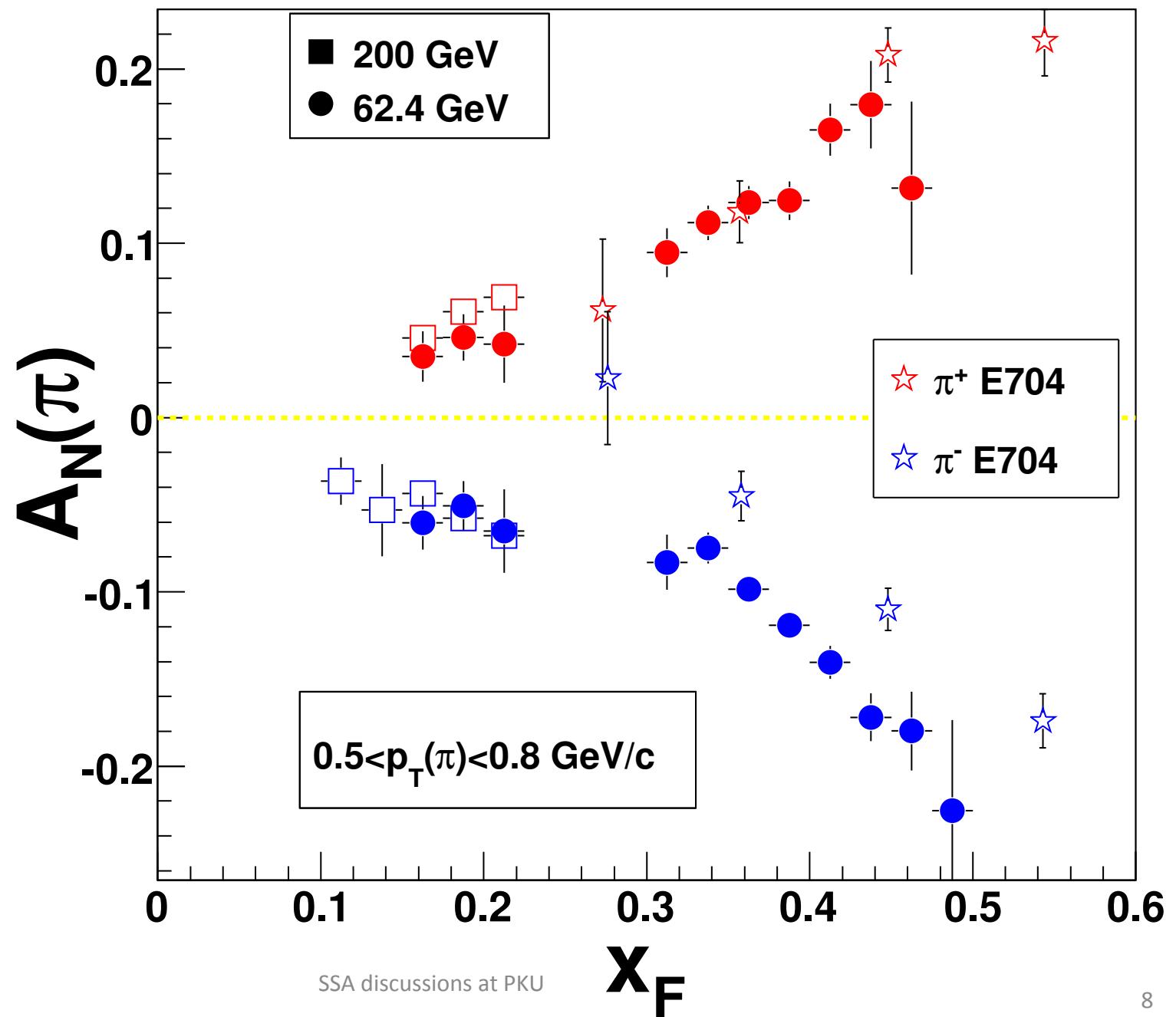
$$A_N \approx \frac{m_q \alpha_S}{p_T}$$

π^0 favors the left side of proton spin vector



At 200 GeV

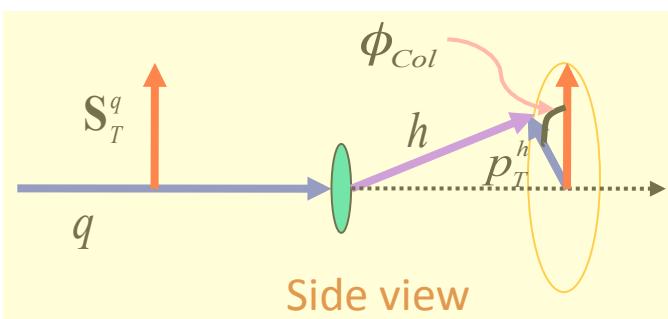
BRAHMS Preliminary



How could a quark tell left from right ?

within the Transverse Momentum Dependent parton distribution (TMD) framework.

- Collins: a transversely polarized quark generates left-right asymmetry in the process of fragmentation.

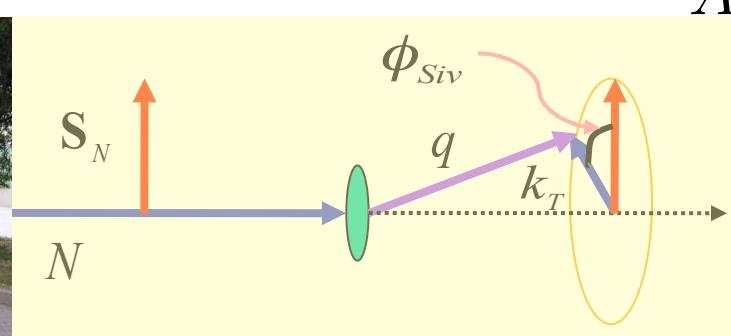


$$A_N^{Collins} \propto \delta q(x) \otimes H_{1q}^{\perp h}(z, P_{h\perp}^2)$$

Transversity: quark's transverse spin.

T-Odd fragmentation function

- Sivers: quark-distribution is left-right asymmetric in a transversely polarized nucleon due to quark's transverse motion.



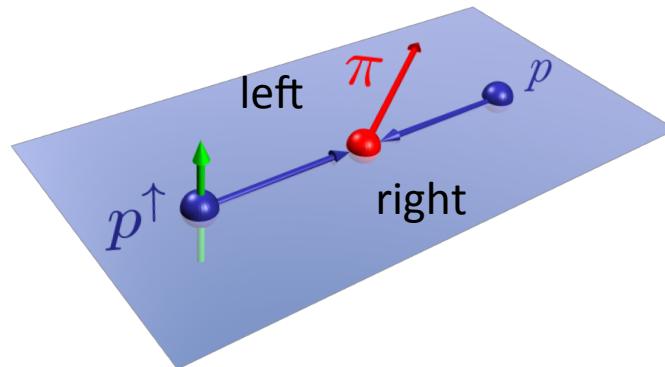
$$A_N^{Sivers} \propto f_{1T}^{\perp q}(x) \otimes D_{1q}^{\perp h}(z, P_{h\perp}^2)$$

T-Odd quark distribution: Sivers distr.

Regular fragmentation function

Valence quarks inside a transversely polarized proton have a very clear left-right bias.

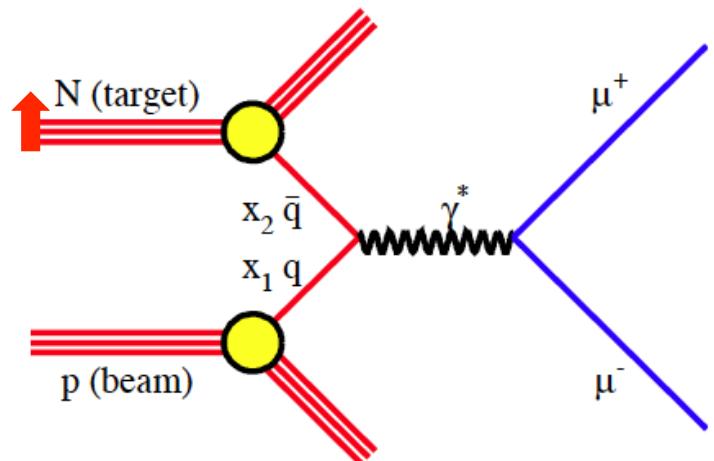
Viewing along the polarized proton's momentum direction,
 π^+ ($u\bar{d}$) favors the left-side, π^- ($d\bar{u}$) favors the right side of the proton spin vector.



**How about sea quarks ?
Do they have a clear left-right bias ?**

Fermilab E-1039

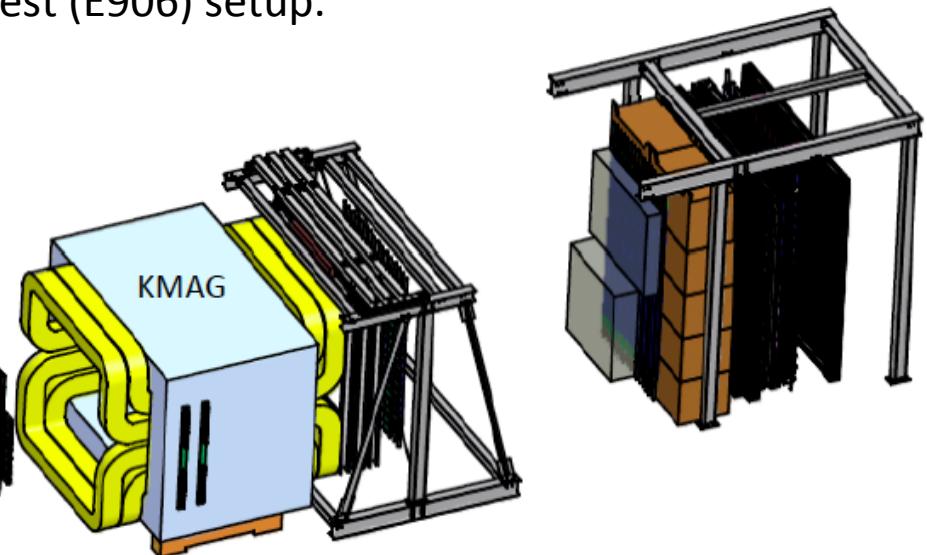
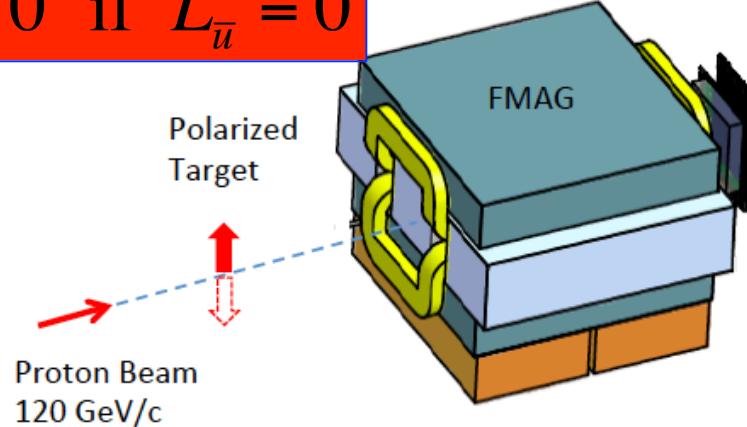
Polarized Target Drell-Yan Single-Spin Asymmetry Measurement to Access Sea Quarks' Angular Momentum



- Measure Drell-Yan yield dependence on the target's spin direction.
- Strong constraints on sea quarks' angular momentum.
- Add a polarized proton (NH_3) target to SeaQuest (E906) setup.

$$A_N = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \neq 0$$

$A_N \equiv 0$ if $L_{\bar{u}} = 0$



When combined with polarized beam in the future, can provide direct accesses to sea quark polarization and transversity.

- Nucleon spin puzzle: ~50% of proton spin is not accounted for. Sea quarks' orbital angular momentum could be a major part of the “missing spin”.
- Quark orbital angular momentum leads to transverse momentum dependent distributions: Sivers distribution.
- Polarized target Drell-Yan asymmetry at SeaQuest (E906) provides a clean access to sea quark Sivers distribution.
- Experimental setup, polarized target, etc.

Drell-Yan yields depend on target's spin direction?

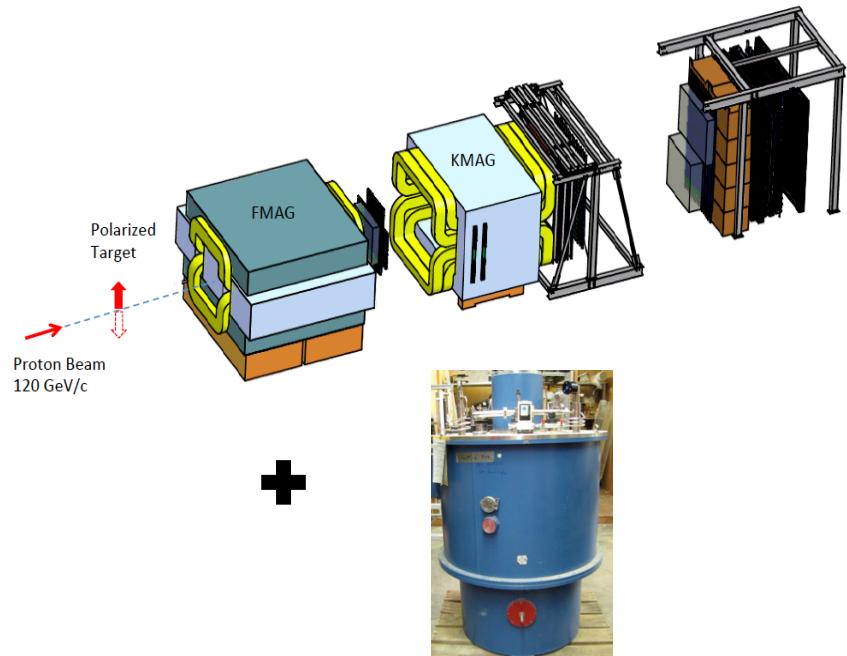
$$A_N = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow} \not\equiv 0$$

$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp, \bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

$$A_N \equiv 0 \quad \text{if } L_{\bar{u}} = 0$$

E-1039 Collaboration:

Co-Spokespersons: A. Klein, X. Jiang
Los Alamos National Laboratory



Collaboration includes experts on

- Drell-Yan: E772, E866, E906
- Polarized target: BNL, SLAC, JLab
- Spin experiments: JLab, HERMES, RHIC

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FNAL Director Granted E-1039 Stage-I Approval

As you can see, the PAC recommends Stage-1 approval for P-1039, contingent on the funding from the DOE Office of Nuclear Physics (NP) for the project and continued minimal impact on the high-priority core program. I accept the PAC recommendation, and grant Stage-1 approval contingent upon funding from the DOE Office of Nuclear Physics. The laboratory management looks forward to discussing with you plans and prospects for obtaining this funding.

Sincerely,

A handwritten signature in blue ink, appearing to read "Piermaria Oddone". The signature is fluid and cursive, with a long horizontal stroke at the bottom.

Piermaria Oddone

Letter-Of-Intend (P-1039): submitted May 4th, 2013.

FNAL PAC presentation: June 6th, 2013.

Stage-I approval: June 26th, 2013.

Polarized Drell-Yan SSA: COMPASS, E-1027 and E-1039

	Beam Pol.	Target Pol.	Favored Quarks	Physics Goal
COMPASS $\pi^- p^\uparrow \rightarrow \mu^+ \mu^- X$	✗	✓	Valence quark	Sign change and size of Sivers distribution for valence quark
E-1027 $p^\uparrow p \rightarrow \mu^+ \mu^- X$	✓	✗	Valence quark	Sign change and size of Sivers distribution for valence quark
E-1039 $p p^\uparrow \rightarrow \mu^+ \mu^- X$	✗	✓	Sea quark	Size and sign of Sivers distribution for Sea quarks, if DY A_N ≠ 0.

Nucleon Spin Puzzle: ~50% of spin is missing

The need for a major breakthrough in understanding the origin of the nucleon spin

Nucleon's $\frac{1}{2}$ spin:

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma_q + L_q + \Delta g + L_g$$

Many years of spin experiments since 1988:

Quark polarization from all flavor:

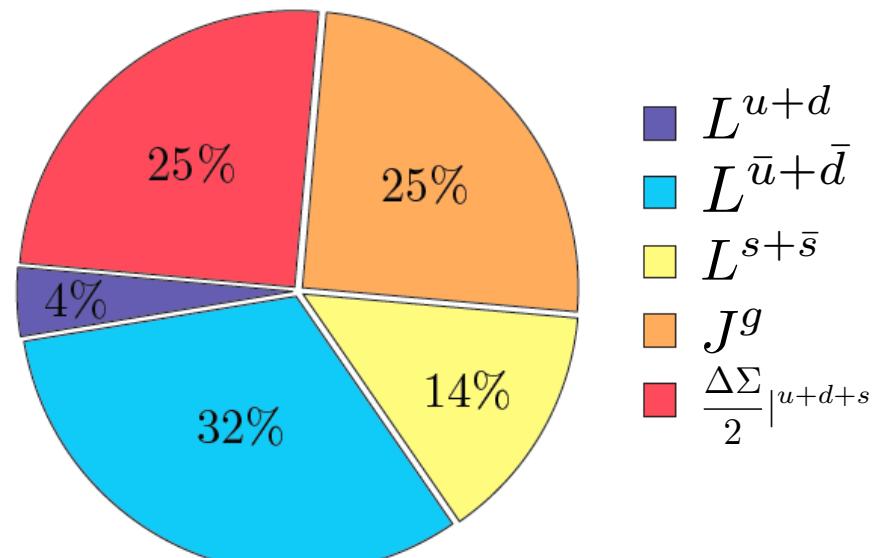
$$\Delta \Sigma_q \approx 0.25 \pm \dots$$

Gluon polarization (RHIC):

$$\int_{0.05}^{0.2} dx \Delta g(x) = 0.1 \pm 0.06$$

about half of the nucleon's spin is not accounted for

Lattice QCD: K.-F. Liu *et al* arXiv:1203.6388



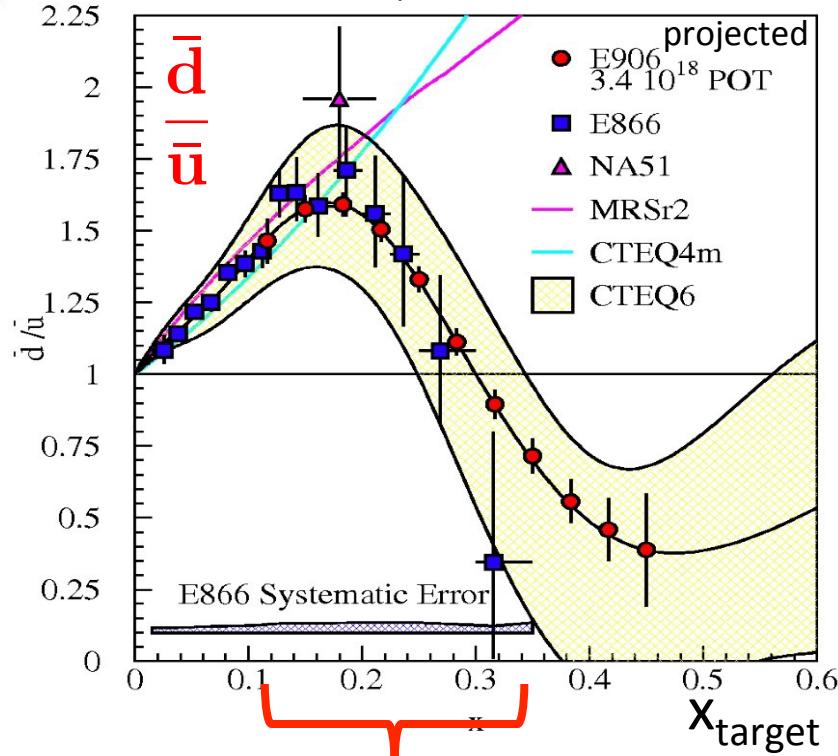
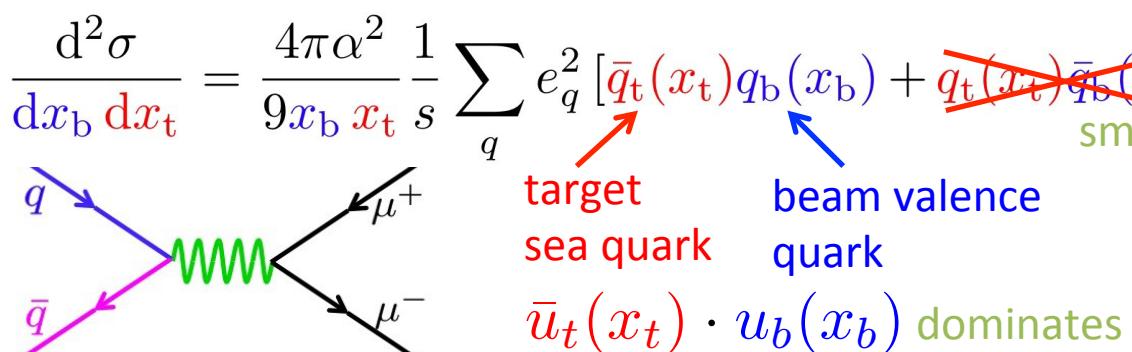
$$\Delta \Sigma_q \approx 25\%$$

$$2 L_q \approx 46\% \text{ (0\% (valence) + 46\% (sea))}$$

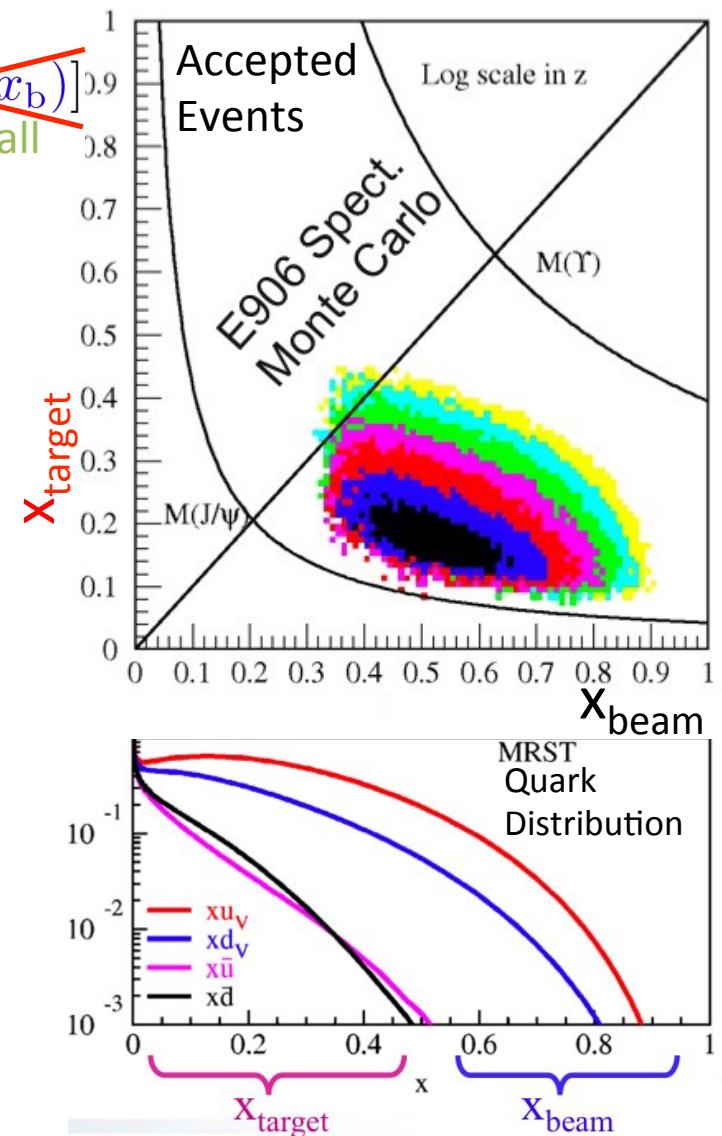
$$2 J_g \approx 25\% \quad L_u \approx -L_d$$

Orbital angular momentum ? Sea quarks' angular momentum could be a major part of the “missing spin”.

Drell-Yan at SeaQuest (E906): a Clean Access to Sea Quark



Strong flavor asymmetry in the sea.



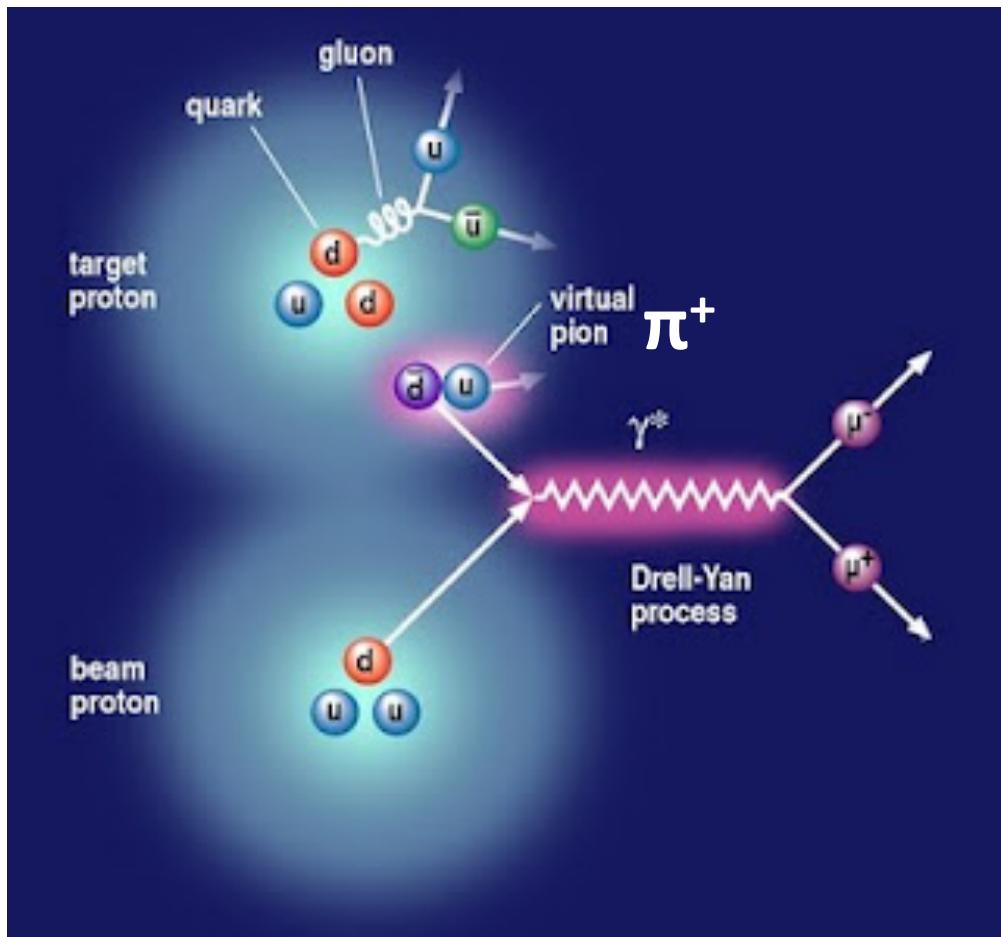
Could sea quarks carry a significant amount of angular momentum ?

12/23/13

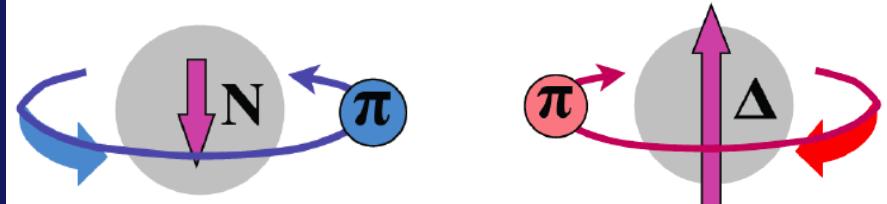
SSA discussions at PKU

The meson cloud model explains the flavor asymmetry in the sea, and requires quarks to carry angular momentum.

$$|p\rangle = p + N\pi + \Delta\pi + \dots$$

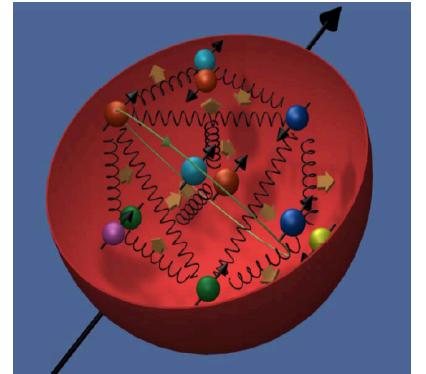


Pions $J^p=0^-$ Negative Parity
Need **L=1** to get proton's $J^p=\frac{1}{2}^+$



Sea quarks should carry orbital angular momentum.

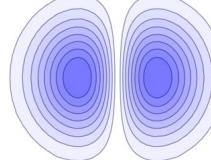
Quark Orbital Momentum and the Sivers Function



The Sivers function is the distribution of **unpolarized** quarks in a transversely polarized proton

$$\vec{L} = \vec{b} \times \vec{k} \quad f_{q/P^\dagger}(x, \mathbf{k}_\perp, S) = f_1(x, \mathbf{k}_\perp^2) - \frac{\mathbf{S} \cdot (\hat{\mathbf{P}} \times \mathbf{k}_\perp)}{M} f_{1T}^\perp(x, \mathbf{k}_\perp^2)$$

quark density 

Sivers distribution 

Sivers distribution was **believed to vanish** until 2002!

- Naive T-odd, not allowed for collinear quarks. Transverse Mom. Dep. parton distributions (TMD).
- Imaginary piece of interference $L_q=0 \otimes L_q=1$ quark wave functions.

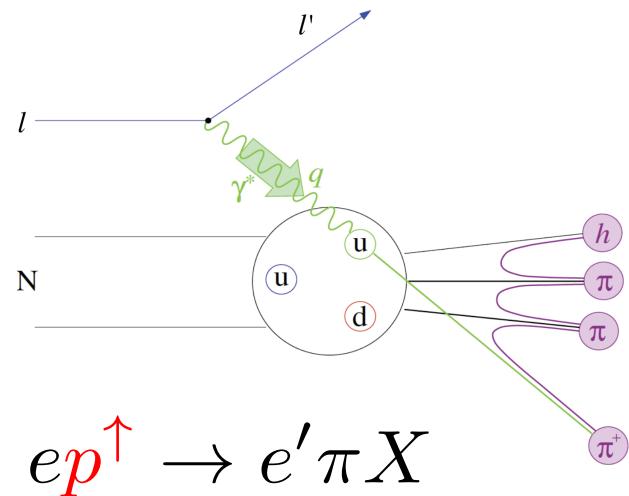
Sivers function = 0 $\longleftrightarrow L_q=0$

Sea quark Sivers function =0 ?

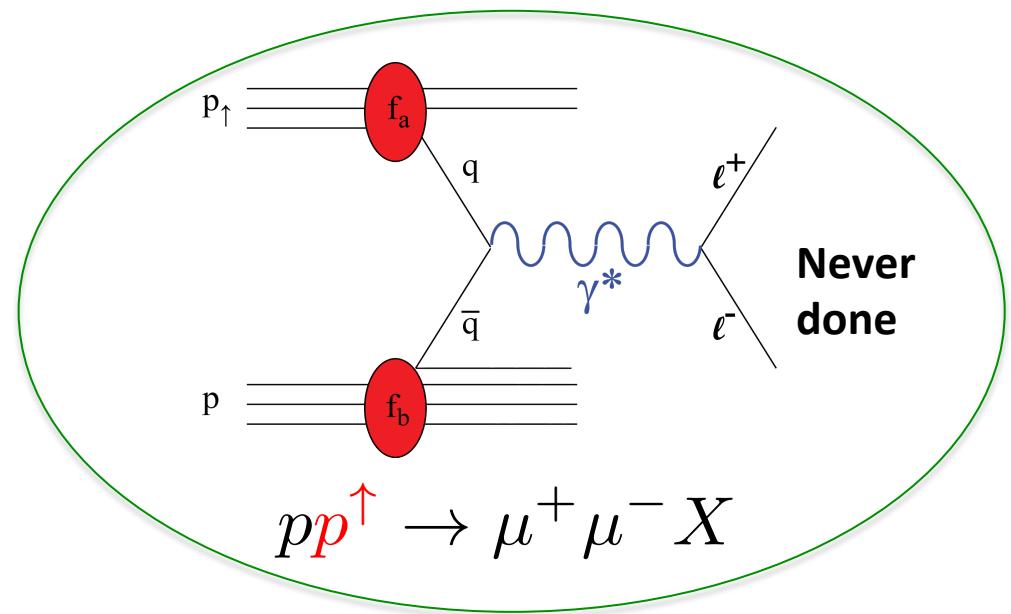
Accessing the quark Sivers distribution

Polarized target experiments

Left-right asymmetry in Semi-Inclusive Deep Inelastic Scattering (SIDIS) on a polarized nucleon



Left-right asymmetry in Drell-Yan di-muon production (DY) on a polarized nucleon

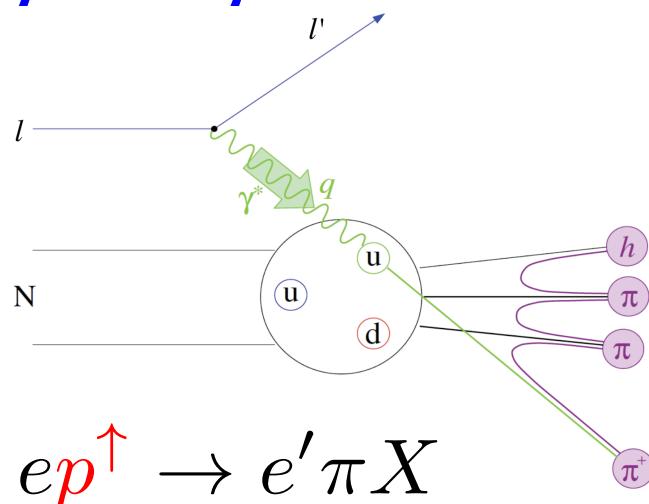


Cornerstone prediction of QCD

The same quark Sivers distribution in both processes, but with **opposite sign**

$$f_{1T}^{\perp q} |_{SIDIS} = - f_{1T}^{\perp q} |_{DY}$$

Asymmetry in Semi-Inclusive DIS

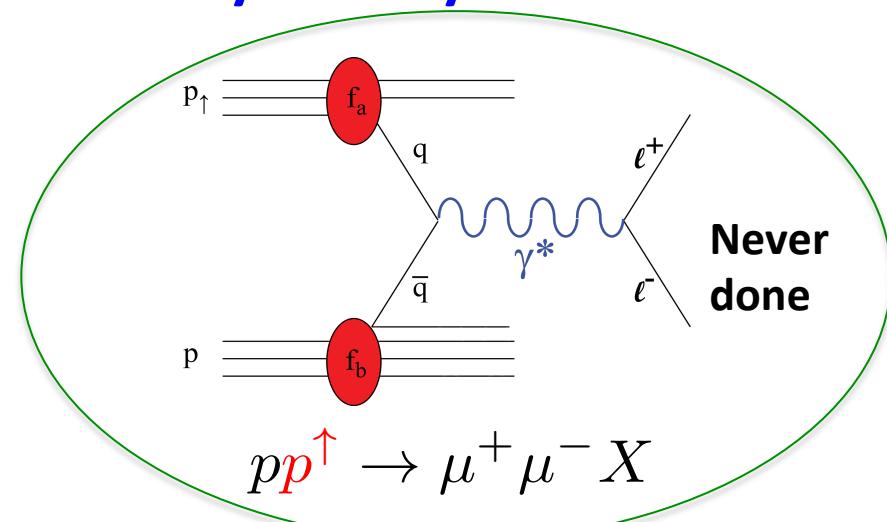


$$d\sigma^{\uparrow\downarrow} = d\sigma_0 \pm \sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)$$

- **Involves quark to hadron frag. func.**
- **Valence and sea quarks are mixed.**

$$A_N = \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x) \otimes D_1^q(z)}$$

Asymmetry in Drell-Yan

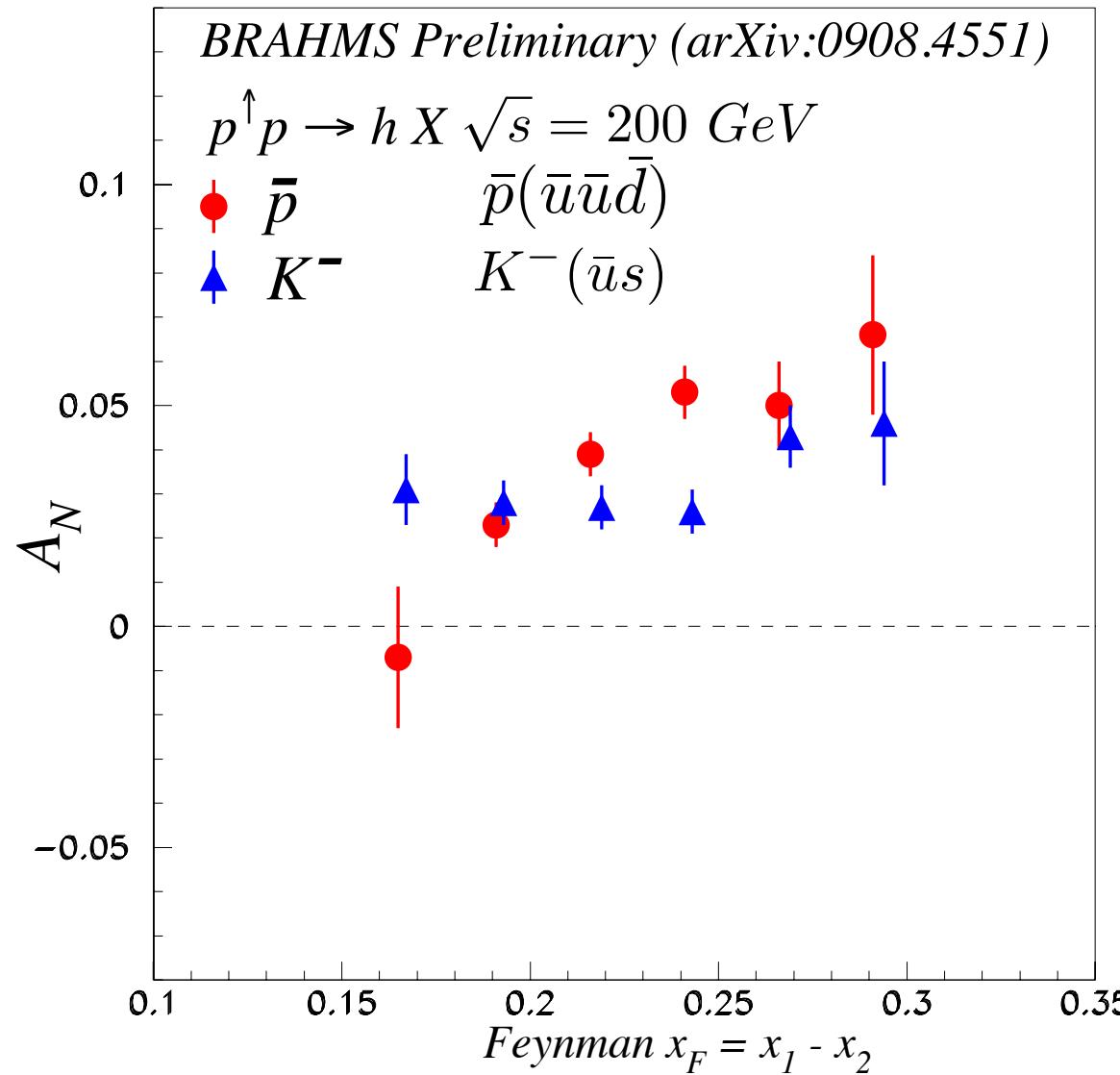


$$d\sigma^{\uparrow\downarrow} = d\sigma_0 \pm \sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2]$$

- **No quark frag. func. involved.**
- **Valence and sea quarks can be isolated**
 - **Pol. Beam \rightarrow valence quark (E-1027)**
 - **Pol. Target \rightarrow sea quark (E-1039)**

$$A_N = \frac{\sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2]}{\sum_q e_q^2 [f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2]}$$

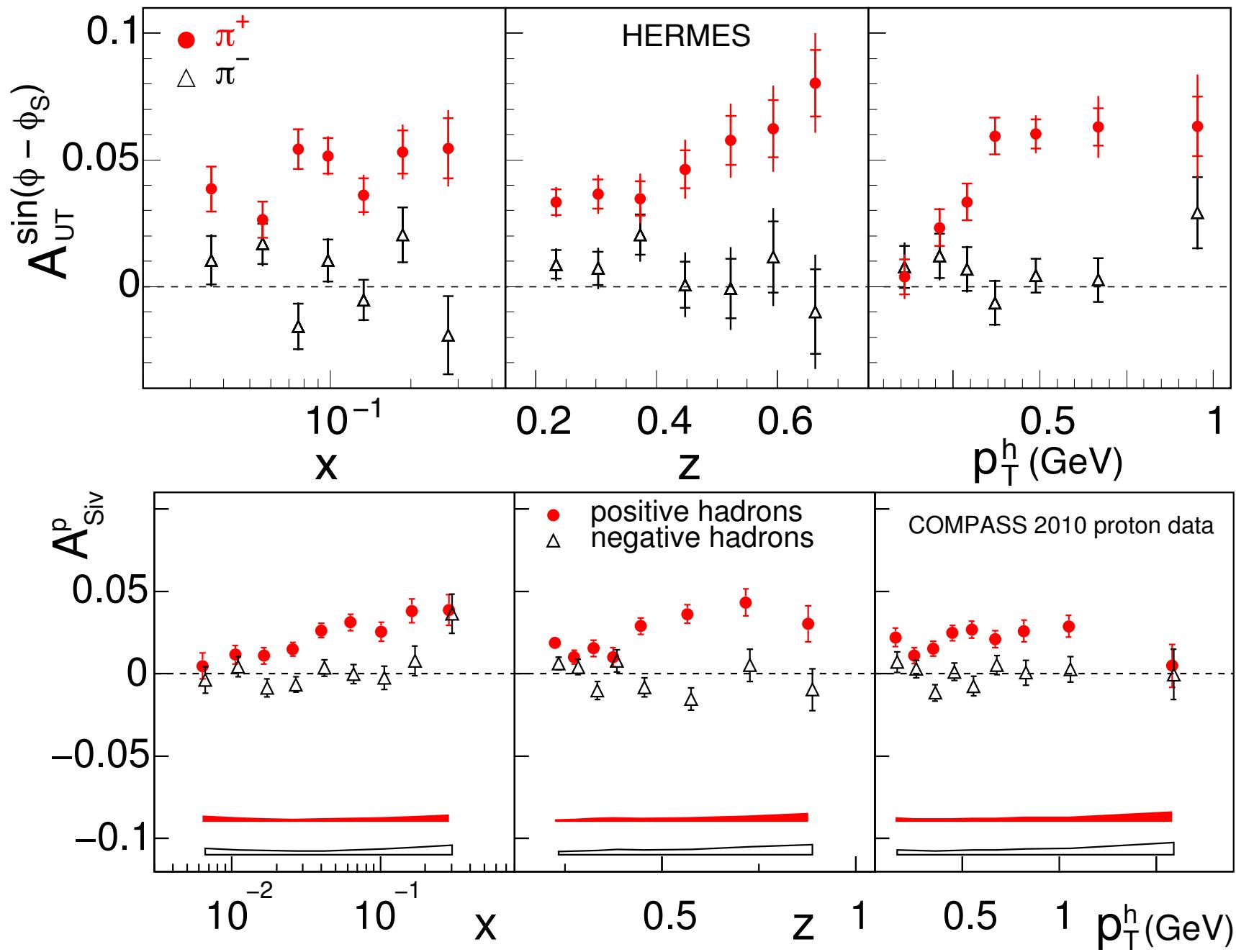
Hints of Non-Vanishing Sea Quark Sivers Distribution ?



Sea quark generates left-right bias ?

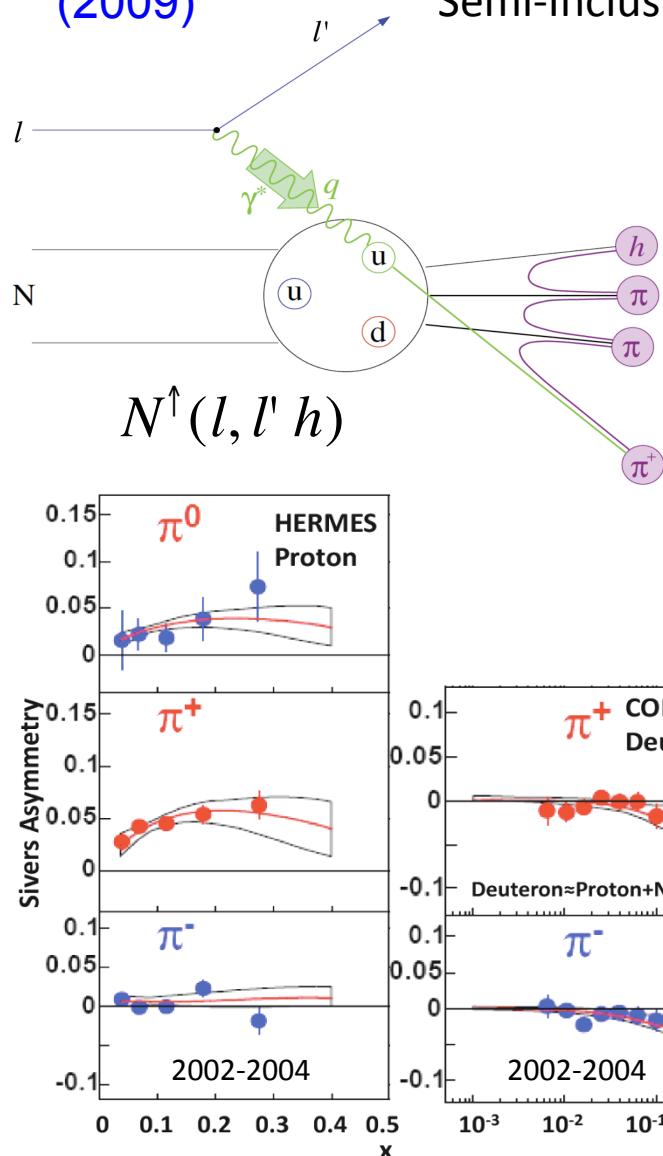
Secondary string-breaking ?

Left-right bias generated through fragmentation process ?



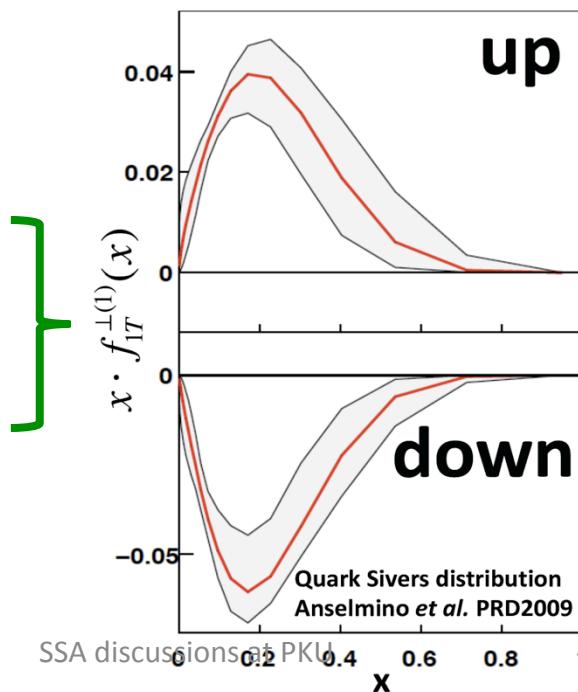
Quark Sivers Distributions: fit to HERMES and COMPASS data (2009)

Semi-Inclusive Deep-Inelastic Scattering on transversely polarized targets



$$A_N = \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x) \otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x) \otimes D_1^q(z)}$$

- Involves quark fragmentation functions.
- Valence quark overwhelmingly dominate.
- Limited sensitivity to sea quark leads to zero sea quark Sivers distribution.
→ large uncertainties in Sivers distribution



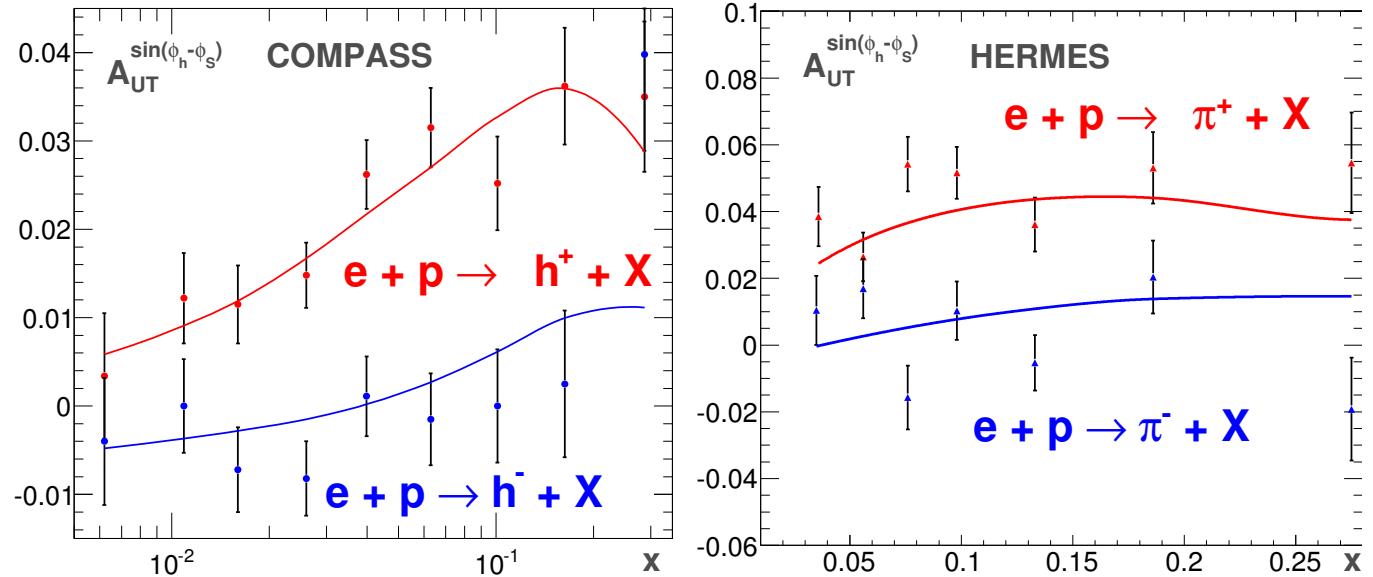
up-quark favors left
($L_u > 0$),

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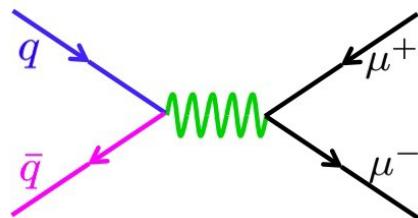
 $L_u \approx -L_d$

Quark Sivers Distributions: a new fit includes new data (2013)

Sun and Yuan:
arXiv:1304.5037

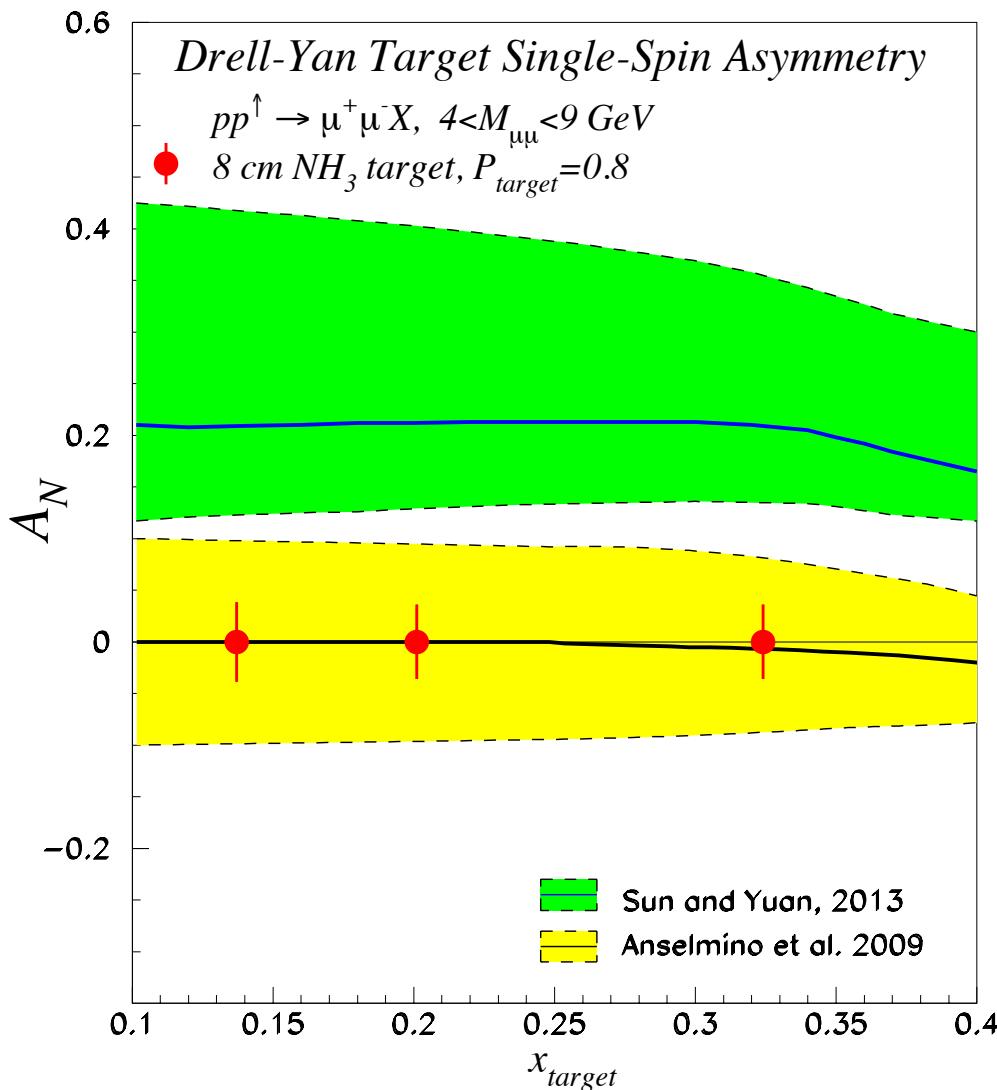


- Include new COMPASS proton target data (2010) and earlier transverse distribution data.
- Take Q^2 -evolution effects into account.
- Allow contributions from sea quarks which lead to non-zeroubar Sivers distribution, however with large error bars.
- Predict Drell-Yan target single-spin asymmetry for SeaQuest.



$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp, \bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

Projected Precision with a Polarized Target at SeaQuest



Statistics shown for one calendar year of running :

$$\mathcal{L}_{\text{int}} = 1.4 * 10^{43} / \text{cm}^2 \leftrightarrow \text{POT} = 2.1 * 10^{18}$$

Approved for two calendar years of beam time

SPN discussions at PKU

$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp, \bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

Existing data do not put enough constraints on the sea quark Sivers distribution, neither in sign nor value.

If $A_N \neq 0$, major discovery:

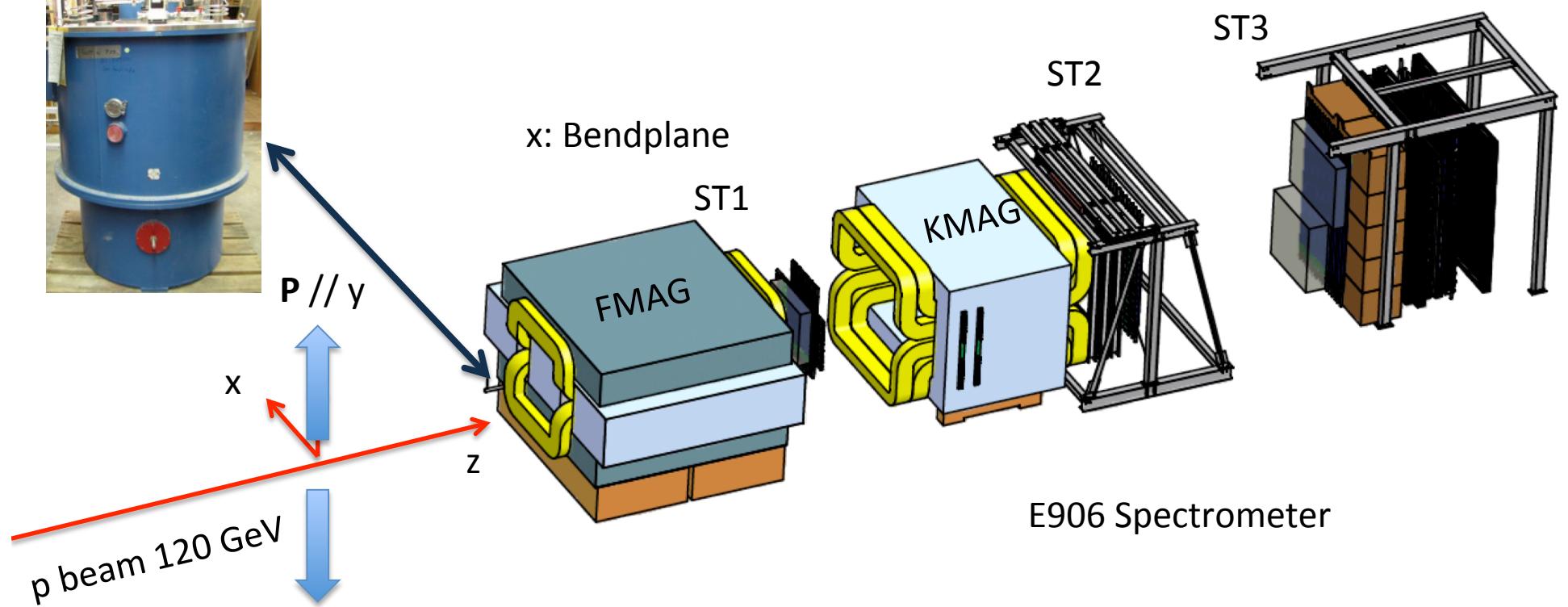
- “Smoking Gun” evidence for $L_{\bar{u}bar} \neq 0$
- Determine sign and value of $\bar{u}bar$ Sivers distribution
- Confirm Lattice QCD and Meson Cloud Model expectations
- Help shape physics direction at EIC

If $A_N = 0$:

- $L_{\bar{u}bar} = 0$, spin puzzle more dramatic ?
- Sea flavor asymmetry hard to explain.
- In contradiction to Lattice QCD and Meson Cloud Model.



A LANL polarized target & E906 Spectrometer

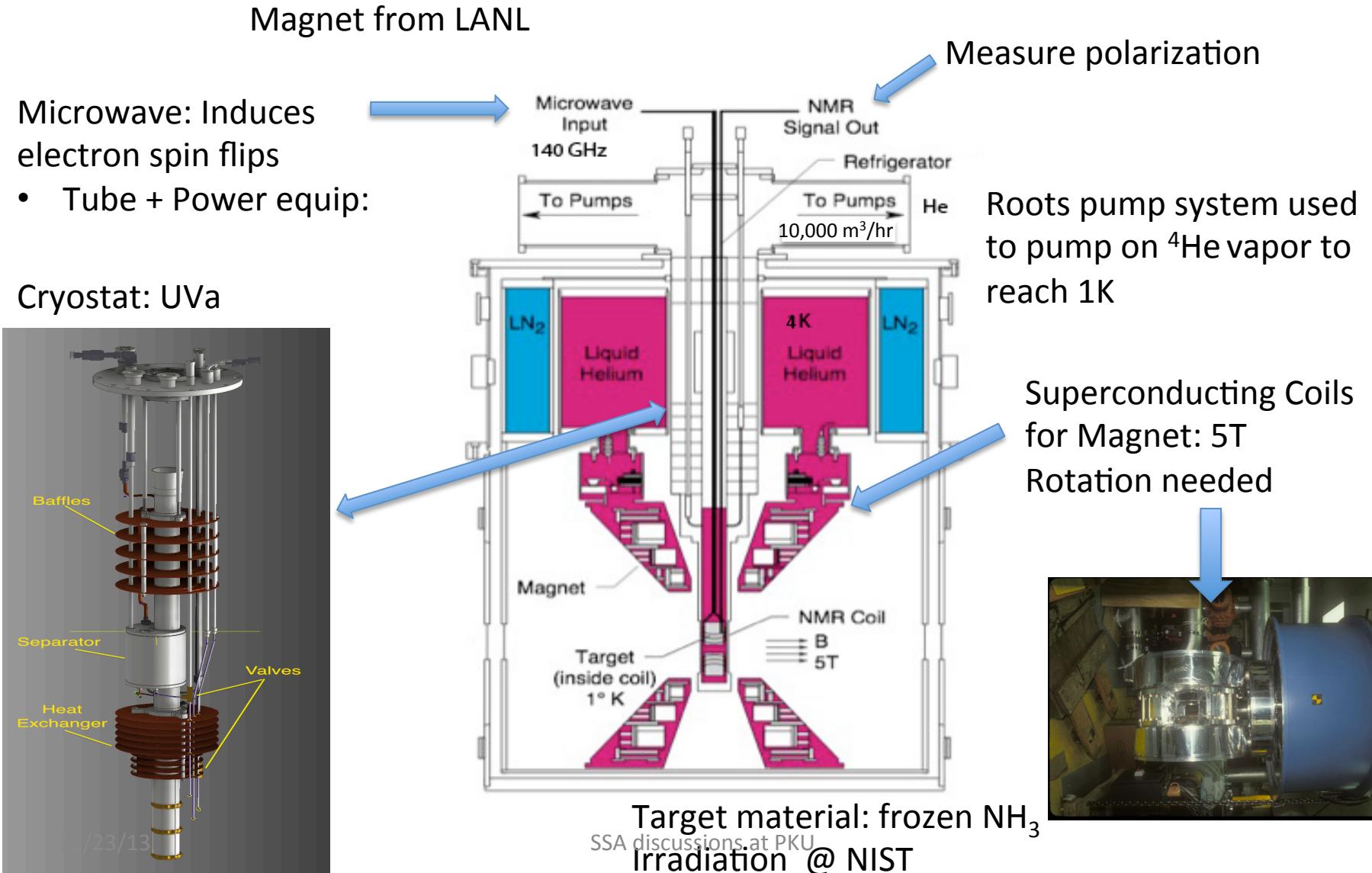


- 4 scintillator hodoscope stations (x and y)
- 4 tracking stations (x and stereos)
- Setup close to E906
- 1×10^{13} p/spill
- Kinematic Range $4 < M < 8$ GeV

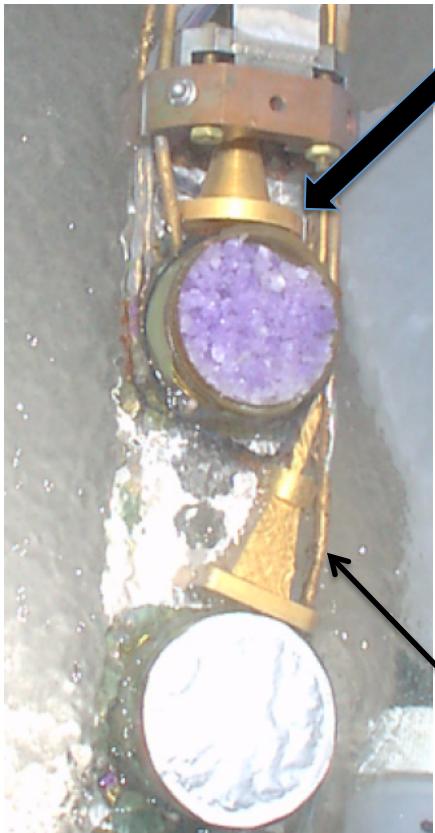
In a similar set up as in FNAL E906

- Can perform world's highest luminosity polarized target Drell-Yan measurement at Fermilab's 120 GeV proton beam

The Polarized Target System (UVa/SLAC/JLab)



NH₃ Target Parameters:



- Cylinder Φ : 4cm (x,y), length 8cm (z)
 - $\rho = .91 \text{ g/cm}^3$ frozen NH₃
 - Packing Fraction = .6
 - Dilution Factor = 3/17 NH₃
 - 5.1 g/cm^2 (NH₃) + $.44 \text{ g/cm}^2$ He
 - $3 * 10^{24}$ nucleons/cm²
- μ-wave horn**

JLAB target

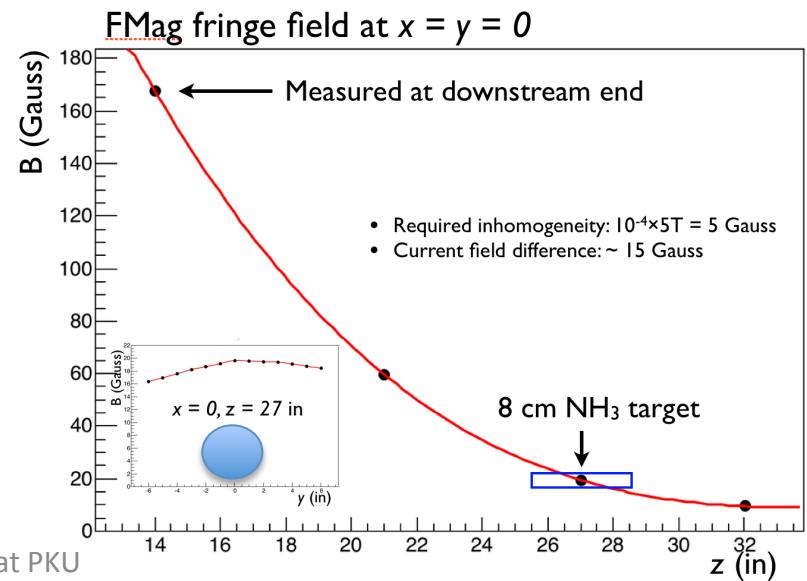
Soft Iron Plate to clamp field from 15G to 5 G

12/23/13

SSA discussions at PKU

Requirements and Running conditions:

- $\frac{\vec{dB}}{\vec{B}} < 10^{-4}$ field uniformity over cell
- μ- wave: 2.2 W +beam: 370mW
- Total heat load **2.6 W**
- 100 liter liquid He/day
- Requires **10,000 m³/hr** pumping capacity



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Hall A G2p
target NIM draft
arXiv:1305.3295

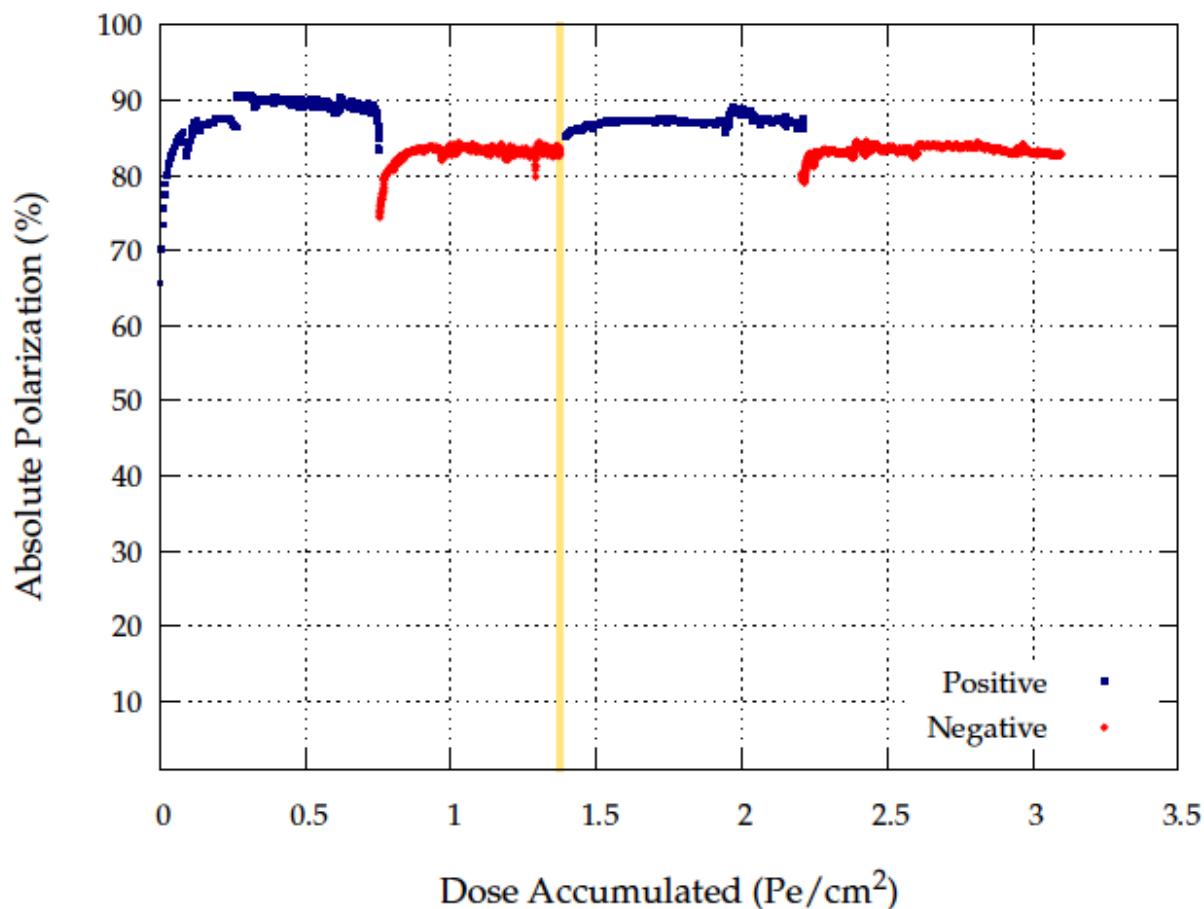
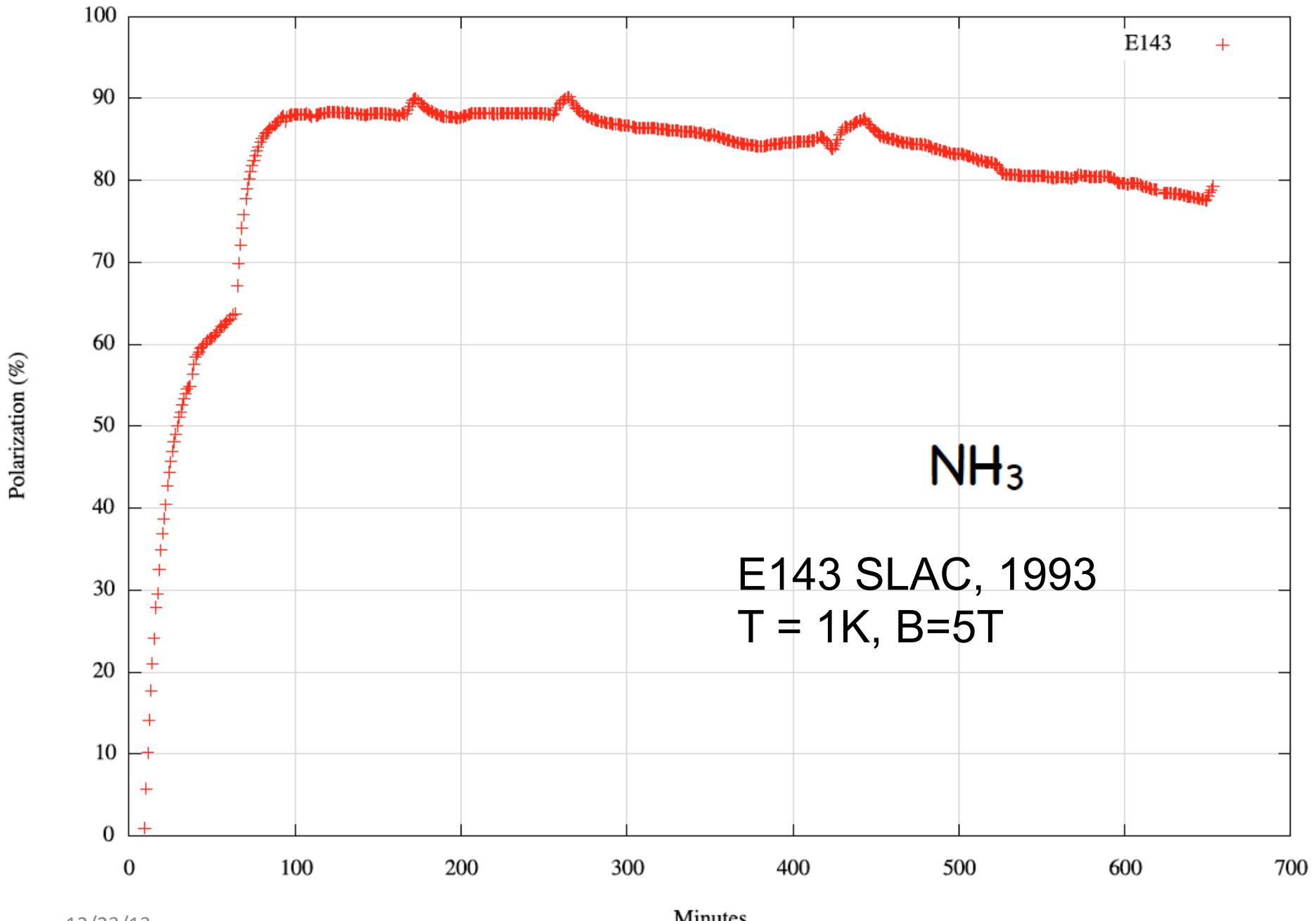
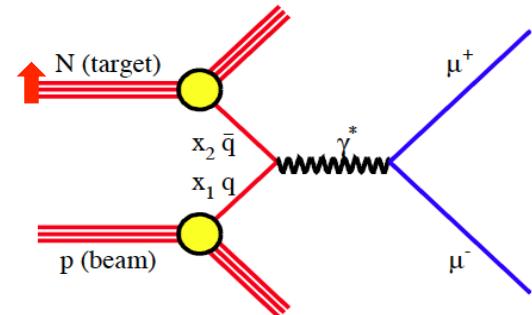


Figure 8: Polarization vs. dose for the material which accounted for over half the total dose accumulated during G_E^P , taken with a 5 T magnet field and 10 nA beam current. The vertical line represents removal and storage at 77 K.



Physics Summary of E-1039



- We know almost nothing about sea quarks angular momentum.
- Quark orbital angular momentum leads to quark Sivers distribution.
- Identifying a non-vanishing sea quark Sivers distribution could lead to a major breakthrough in nucleon structure.
- Polarized target D-Y at Fermilab's SeaQuest provides an unique opportunity to pin down sea quark's angular momentum.

Does Drell-Yan yield depend on target's spin direction?

$$A_N = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow} \stackrel{?}{=} 0$$

$(A_N \equiv 0 \text{ if } L_{\bar{u}} = 0)$

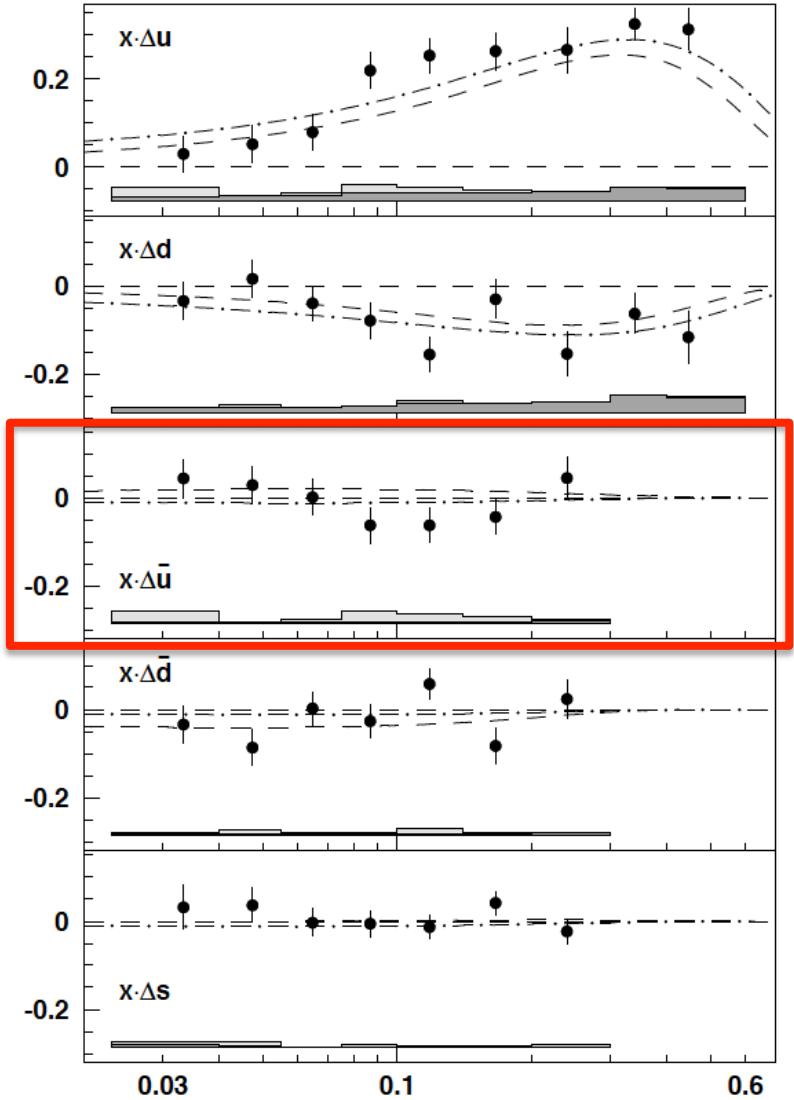
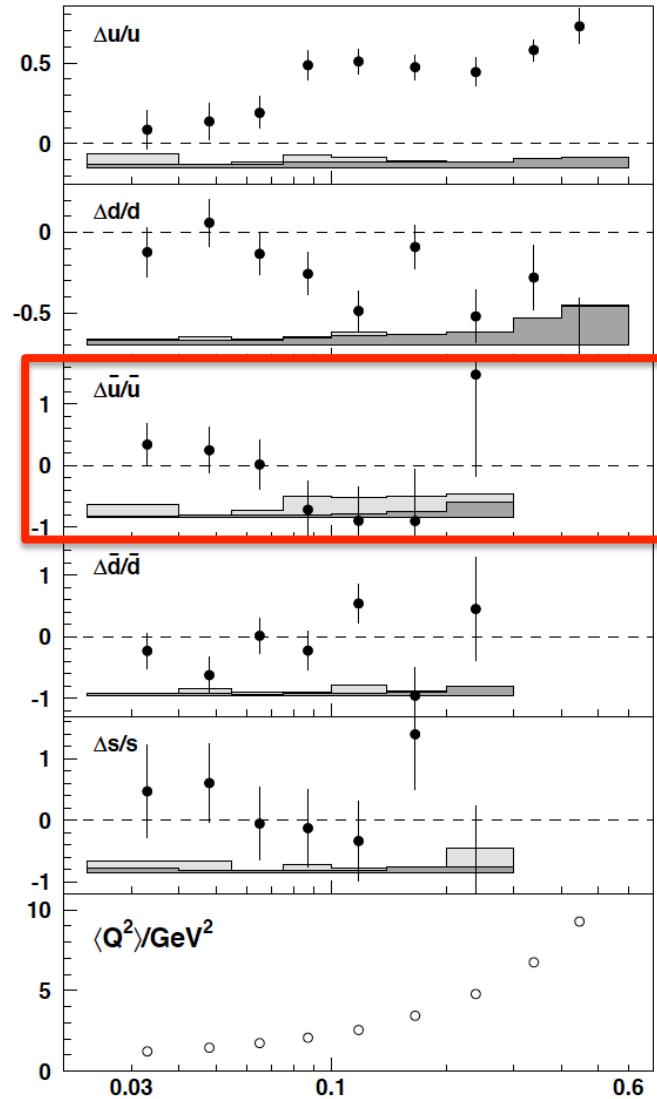
$$A_N^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{\perp, \bar{u}}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}$$

Beyond Drell-Yan Single Spin Asymmetry ...

In the longer term future, if we have both polarized beam and polarized target. Drell-Yan double-spin asymmetry can provide accesses to sea quark's

- **Polarization (A_{LL})**
- **Transversity (A_{TT})**

HERMES 2005 Results of Spin-Flavor Decomposition: from SIDIS Double-Spin Asymmetries

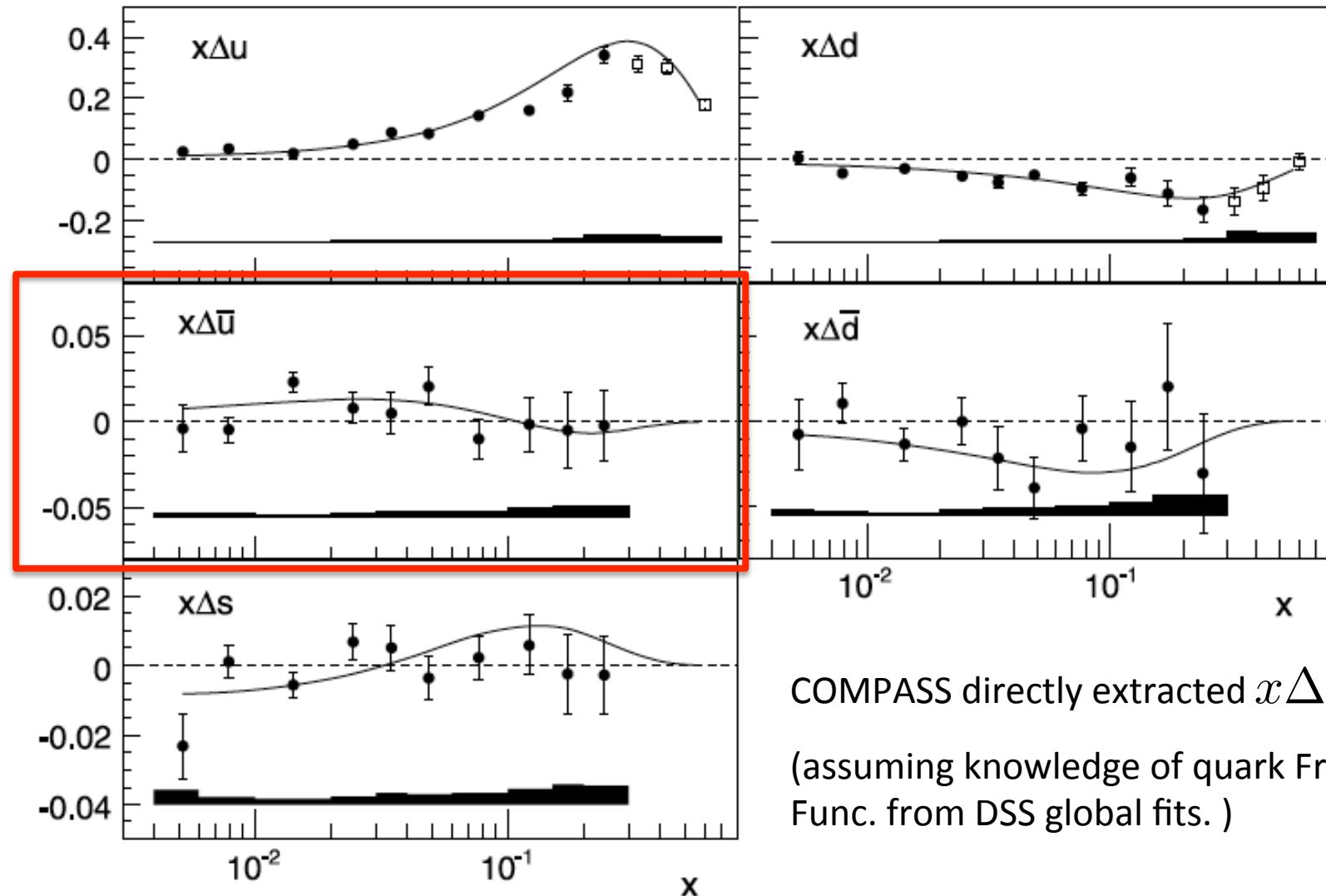


12/23/13

(assuming knowledge of quark Frag. Func. from Monte Carlo simulations.)

x SSA discussions at PKU

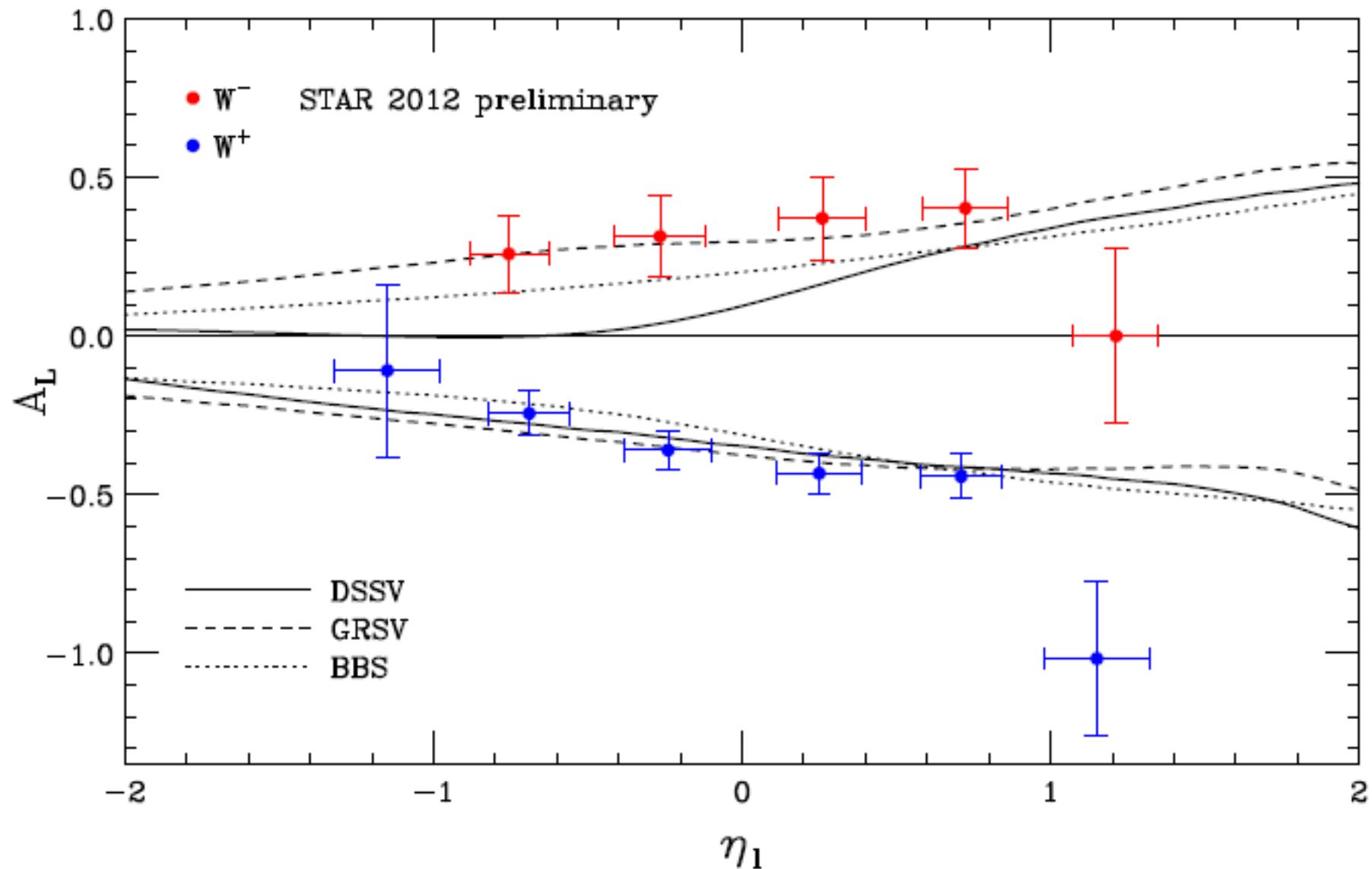
COMPASS 2010 Spin-Flavor Decomposition



COMPASS directly extracted $x\Delta\bar{u}$
 (assuming knowledge of quark Frag.
 Func. from DSS global fits.)

COMPASS data are not shown in fsPHENIX plot, not sure how to propagate error bars to $\Delta\bar{u}/\bar{u}$

STAR Data



Soffer, Trento Nucleon Sea Workshop, July, 2013
12/23/13 SSA discussions at PKU

We define Drell-Yan longitudinally polarized beam-target double-spin asymmetry A_{LL} as:

$$A_{LL}^{DY} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\Delta\sigma_{DY}}{\sigma_{DY}}$$

i.e, the ratio of the difference over the sum (or asymmetry) between the spin-aligned and spin-anti-aligned Drell-Yan cross sections, at the Leading Order, we have:

$$A_{LL}^{DY} = -\frac{\sum_q e_q^2 \{ \Delta q(x_1) \Delta \bar{q}(x_2) + \Delta \bar{q}(x_1) \Delta q(x_2) \}}{\sum_q e_q^2 \{ q(x_1) \bar{q}(x_2) + \bar{q}(x_1) q(x_2) \}}$$

$$A_{pp} \approx -\frac{\Delta u_1}{u_1} \frac{\Delta \bar{u}_2}{\bar{u}_2} \quad A_{pn} \approx -\frac{\Delta u_1}{u_1} \frac{\Delta \bar{d}_2}{\bar{d}_2}$$

if anti-quarks carry no spin $\rightarrow A_{LL}^{DY} \equiv 0 !!!$

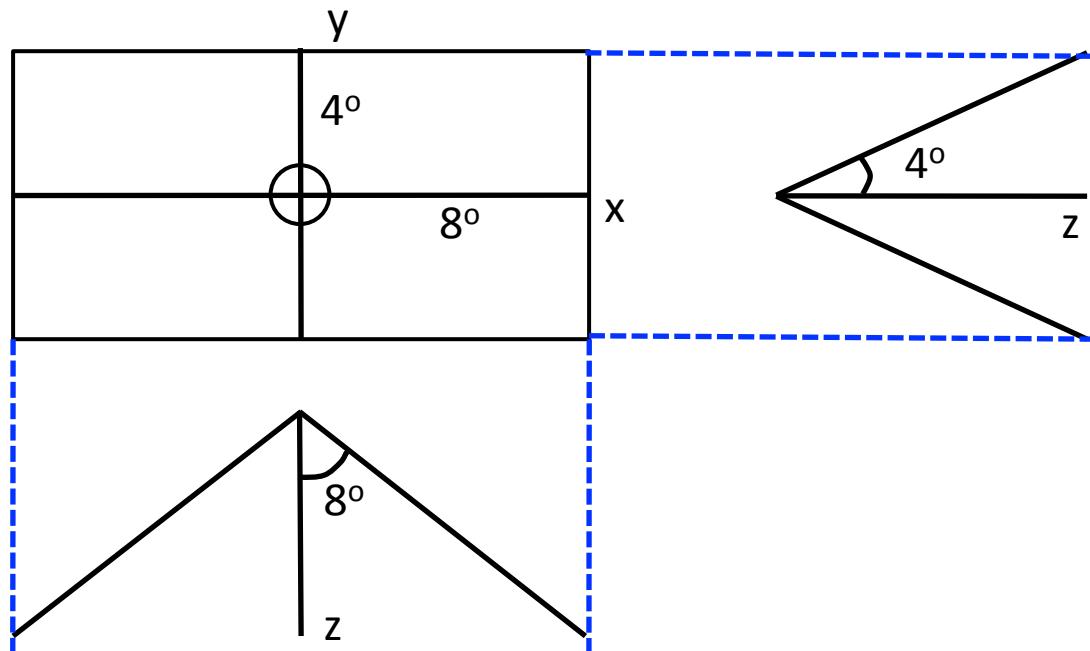
$$A_{LL}^{DY} = -\frac{\sum_q e_q^2 \{ \Delta q(x_1) \Delta \bar{q}(x_2) + \Delta \bar{q}(x_1) \Delta q(x_2) \}}{\sum_q e_q^2 \{ q(x_1) \bar{q}(x_2) + \bar{q}(x_1) q(x_2) \}}$$

$$A_{pp} = -\frac{4\Delta u_1 \Delta \bar{u}_2 + \Delta d_1 \Delta \bar{d}_2 + \dots}{4u_1 \bar{u}_2 + d_1 \bar{d}_2 + \dots}$$

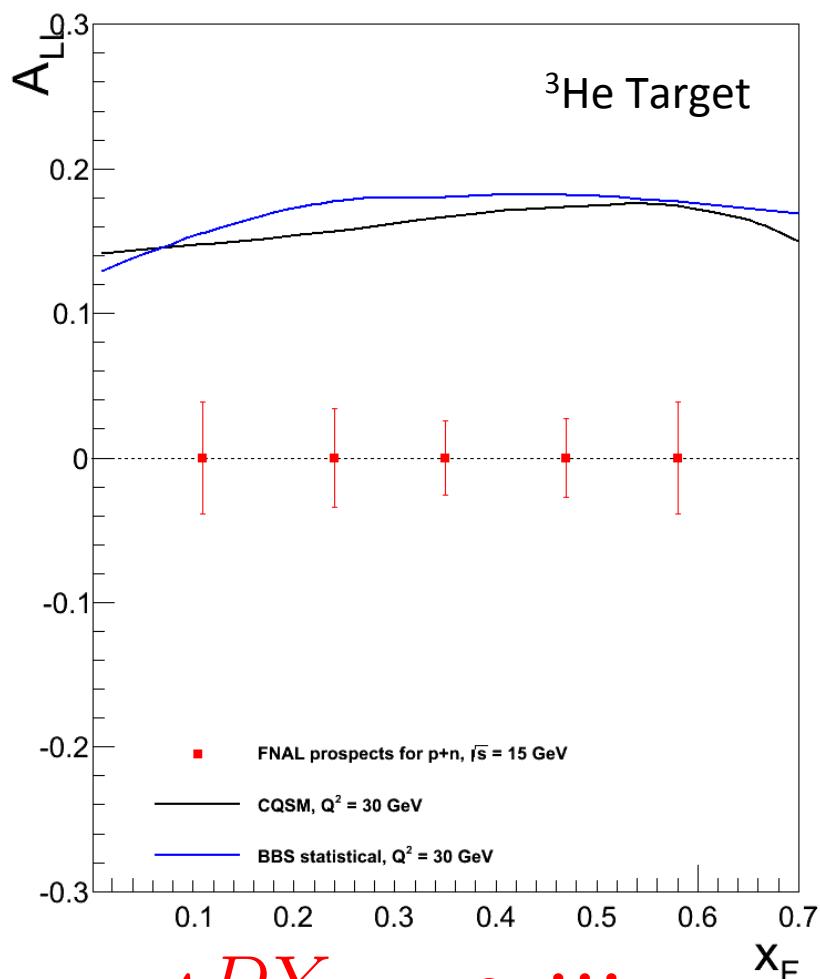
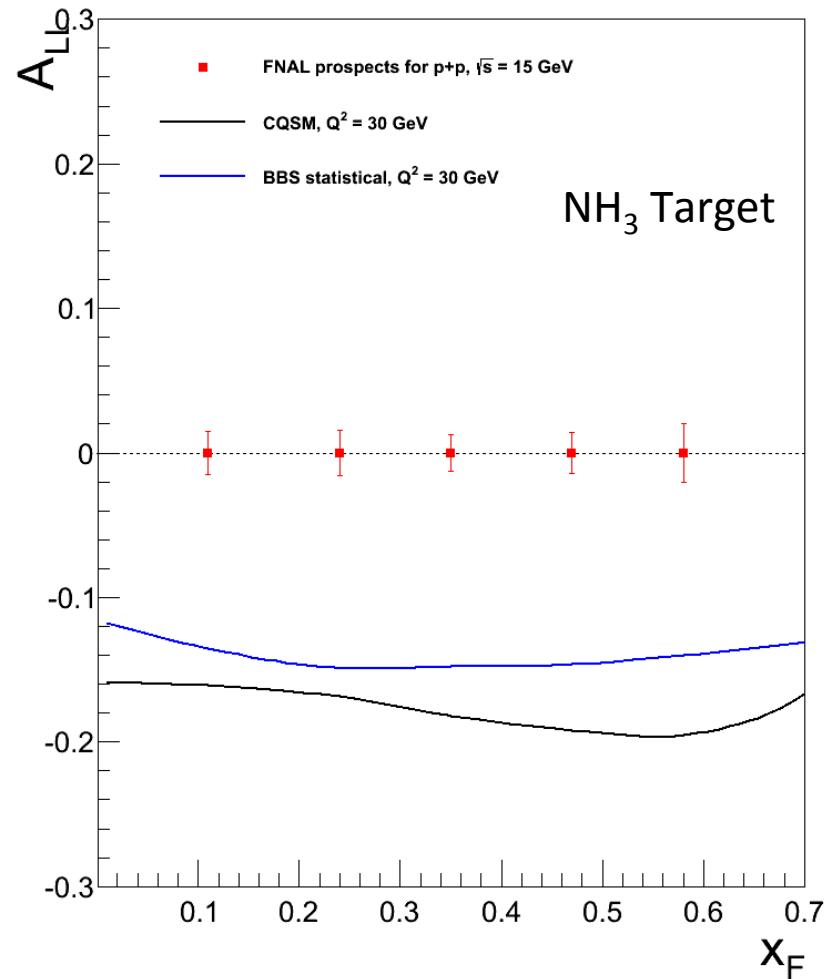
$$A_{pn} = -\frac{4\Delta u_1 \Delta \bar{d}_2 + \Delta d_1 \Delta \bar{u}_2 + \dots}{4u_1 \bar{d}_2 + d_1 \bar{u}_2 + \dots}$$

Geometry of an “ideal” spectrometer for FNAL Drell-Yan

- Vertical acceptance ± 4 degree
- Horizontal acceptance ± 8 degree
- Beam line ± 1 degree



FNAL "prospected data" vs. theory predictions

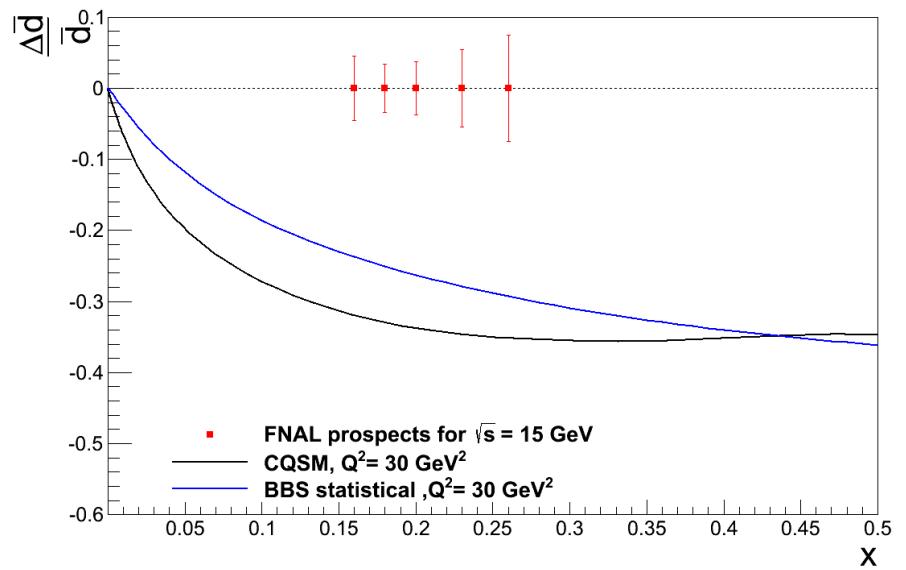
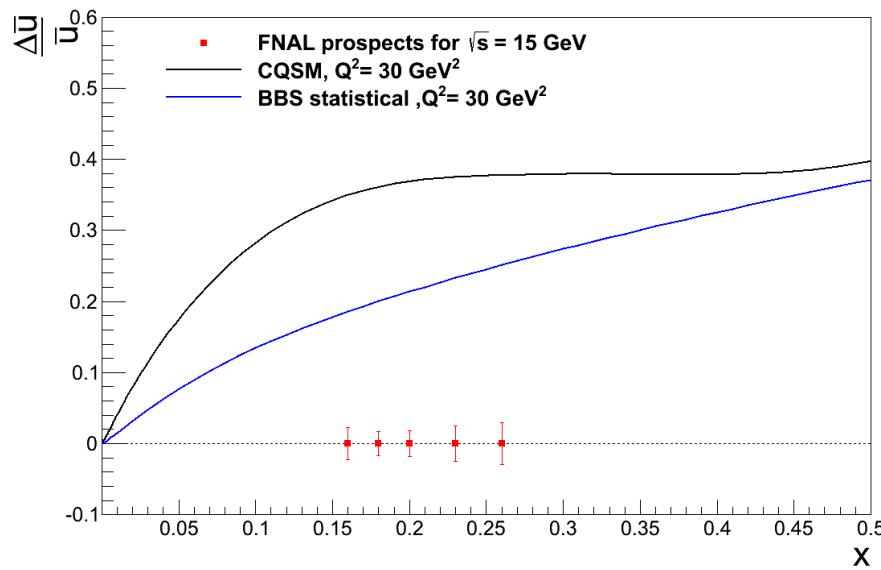


if anti-quarks carry no spin $\rightarrow A_{LL}^{DY} \equiv 0 !!!$

Chiral Quark Soliton Model: Wakamatsu, 2010
 12/29/15 SSA discussions at JLAB

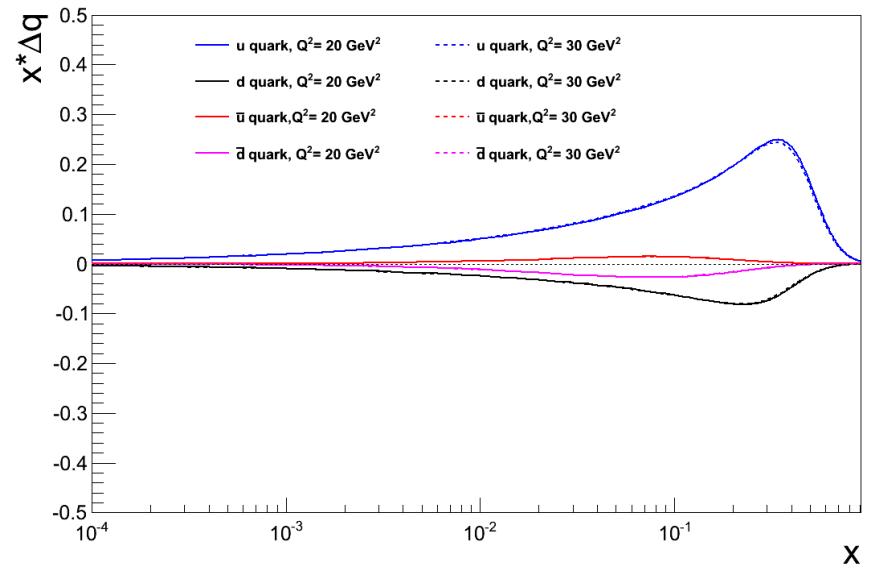
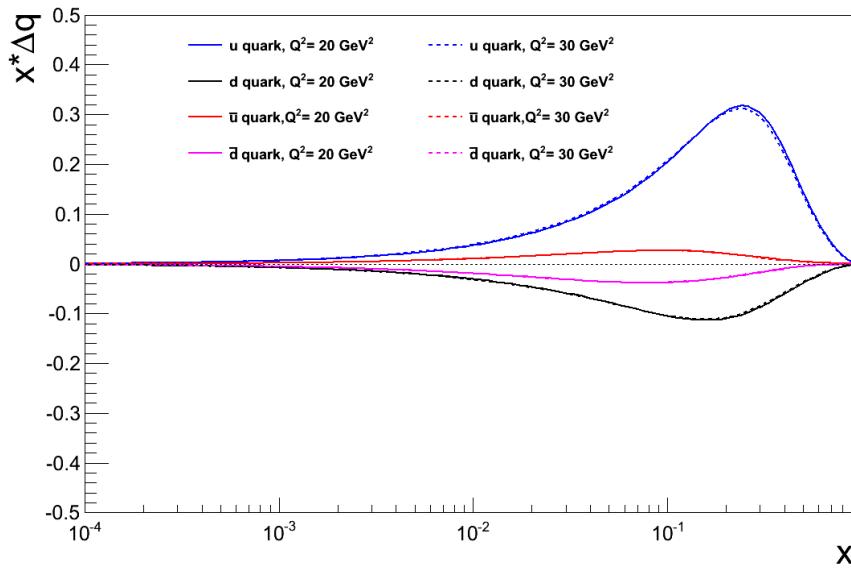
BBS statistical model: Soffer et al 2004.

Translate into $\Delta\bar{u}/\bar{u}$, $\Delta\bar{d}/\bar{d}$ - Fermilab kinematics



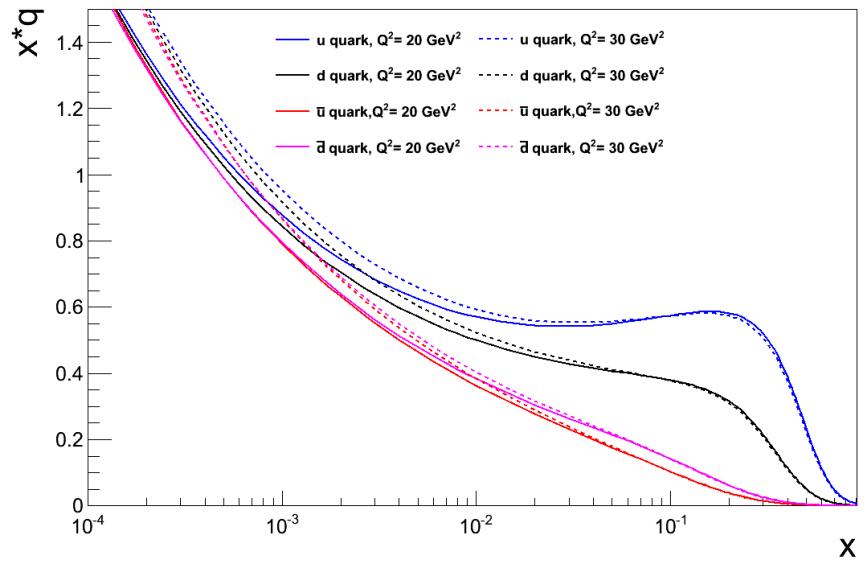
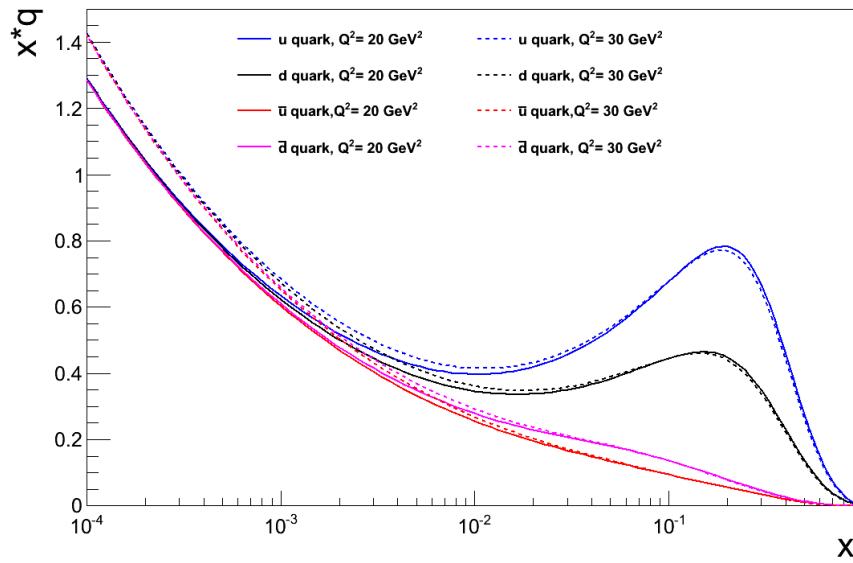
Chiral Quark Soliton Model: Wakamatsu, 2010. BBS statistical model: Soffer et al 2004.

Polarized PDF



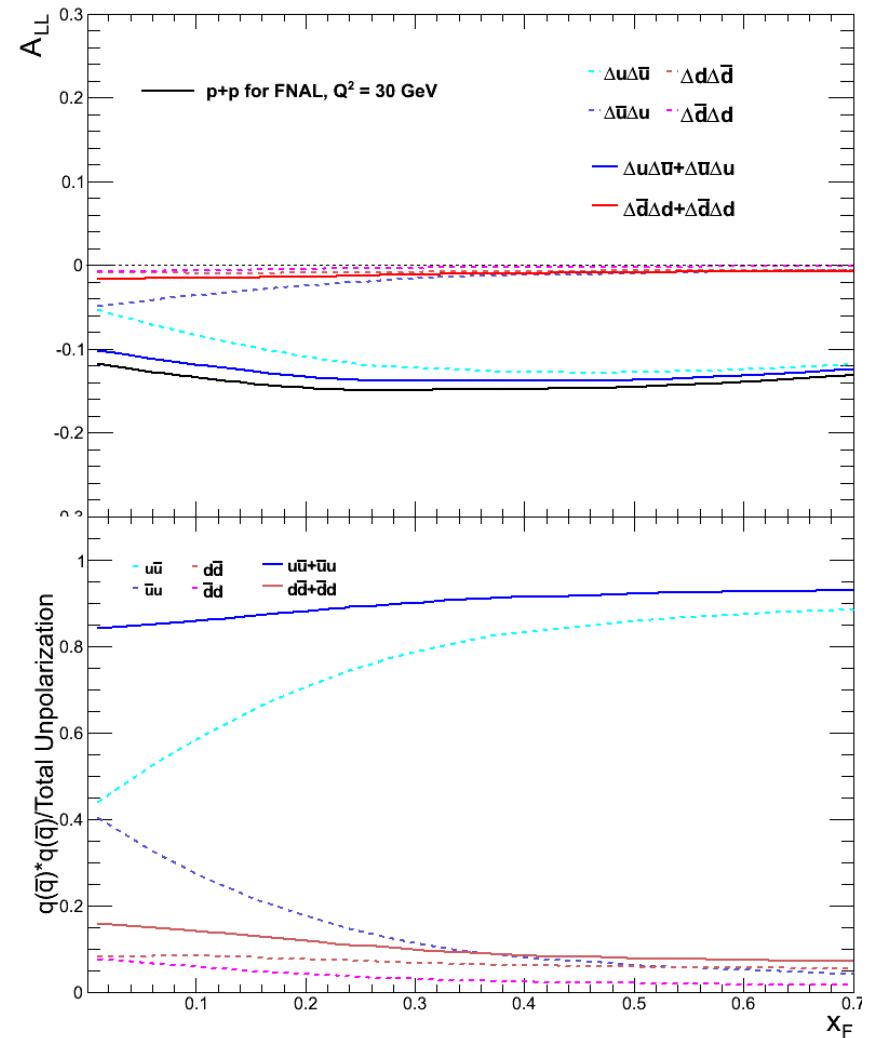
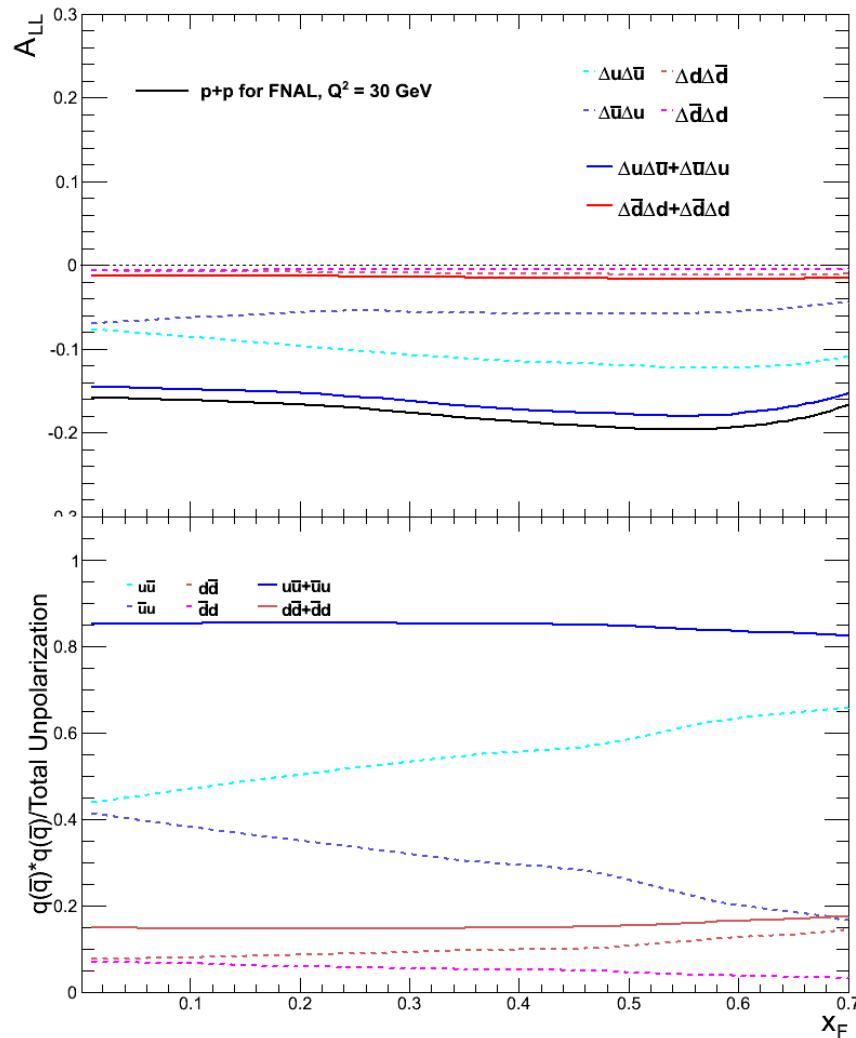
Chiral Quark Soliton Model: Wakamatsu, 2010. BBS statistical model: Soffer et al 2004.

Unpolarized PDF



Chiral Quark Soliton Model: Wakamatsu, 2010. BBS statistical model: Soffer et al 2004.

A_{LL} of FNAL p+p DY Break into Flavors



Chiral Quark Soliton Model: Wakamatsu, 2010. BBS statistical model: Soffer et al 2004.

A_{TT} to Access Transversity

$$A_{TT}^{DY} = \frac{\sin^2 \theta \cos 2\phi}{1 + \cos^2 \theta} \cdot \frac{\sum_q e_q^2 \{ \delta q(x_1) \delta \bar{q}(x_2) + \delta \bar{q}(x_1) \delta q(x_2) \}}{\sum_q e_q^2 \{ q(x_1) \bar{q}(x_2) + \bar{q}(x_1) q(x_2) \}}$$

where θ is the polar angle of either lepton in the rest frame of the virtual photon, and ϕ is the azimuthal angle between the direction of the polarization and the normal to the plane of the di-lepton decay.

$\langle \cos(2\phi) \rangle \approx 2/\pi$, if cover all DY azimuthal angles.

$$\left\langle \frac{\sin^2 \theta}{1 + \cos^2 \theta} \right\rangle = 0.821 \quad \text{for the "idea spectrometer" setup.}$$

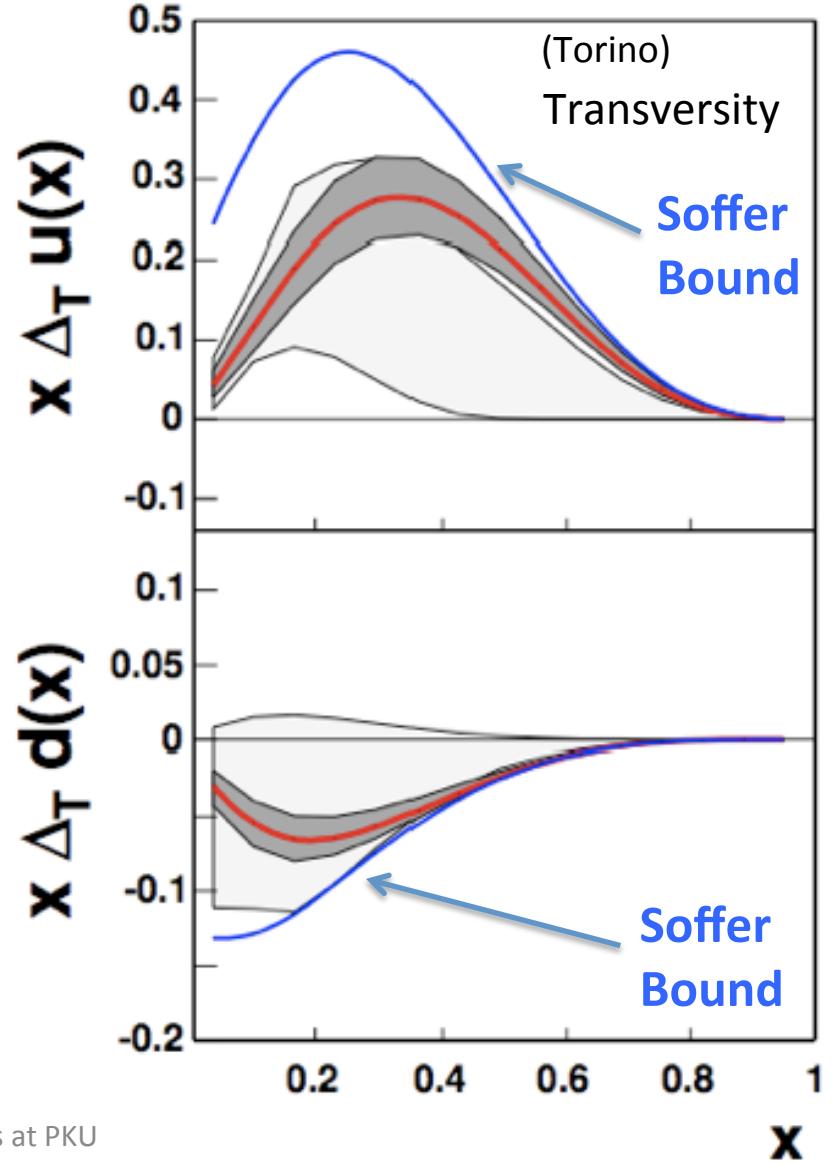
Lacking knowledge on sea transversity, we took the Soffer (positivity) bounds for anti-quark:

$$\delta q(x) \leq \frac{1}{2} |q(x) + \Delta q(x)| \quad \delta \bar{q}(x) \leq \frac{1}{2} |\bar{q}(x) + \Delta \bar{q}(x)|$$

Valance quark transversity from Anselmino group's fit.

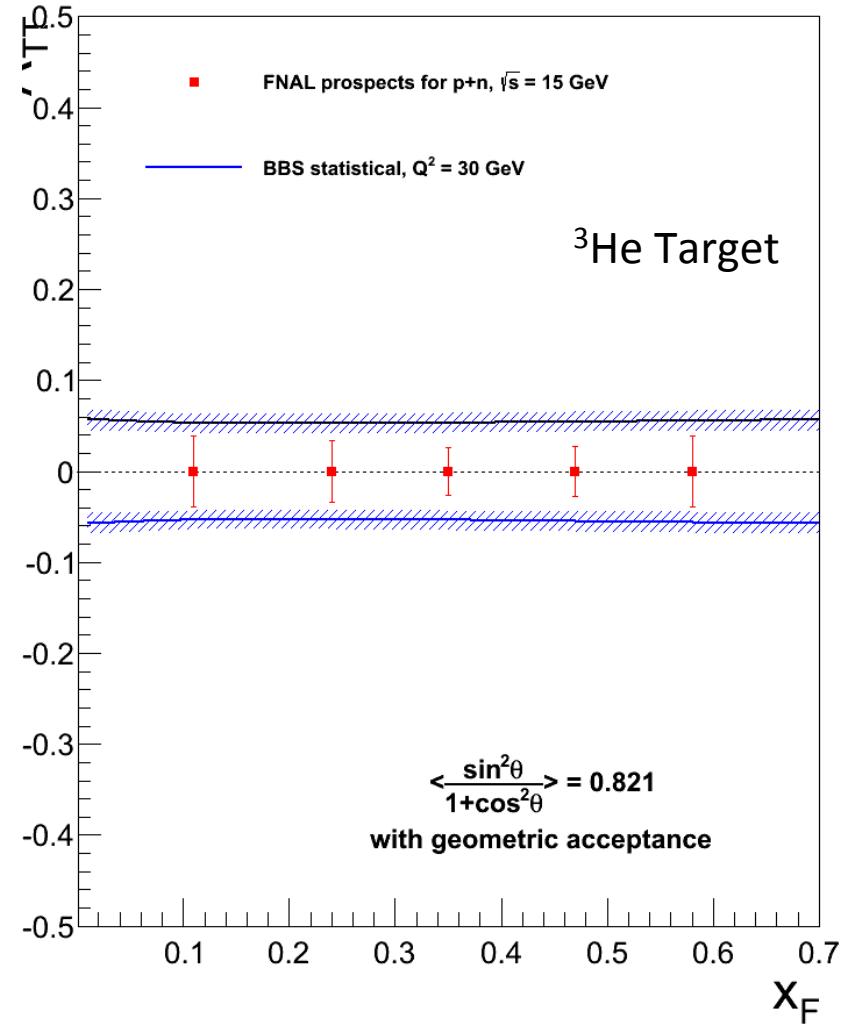
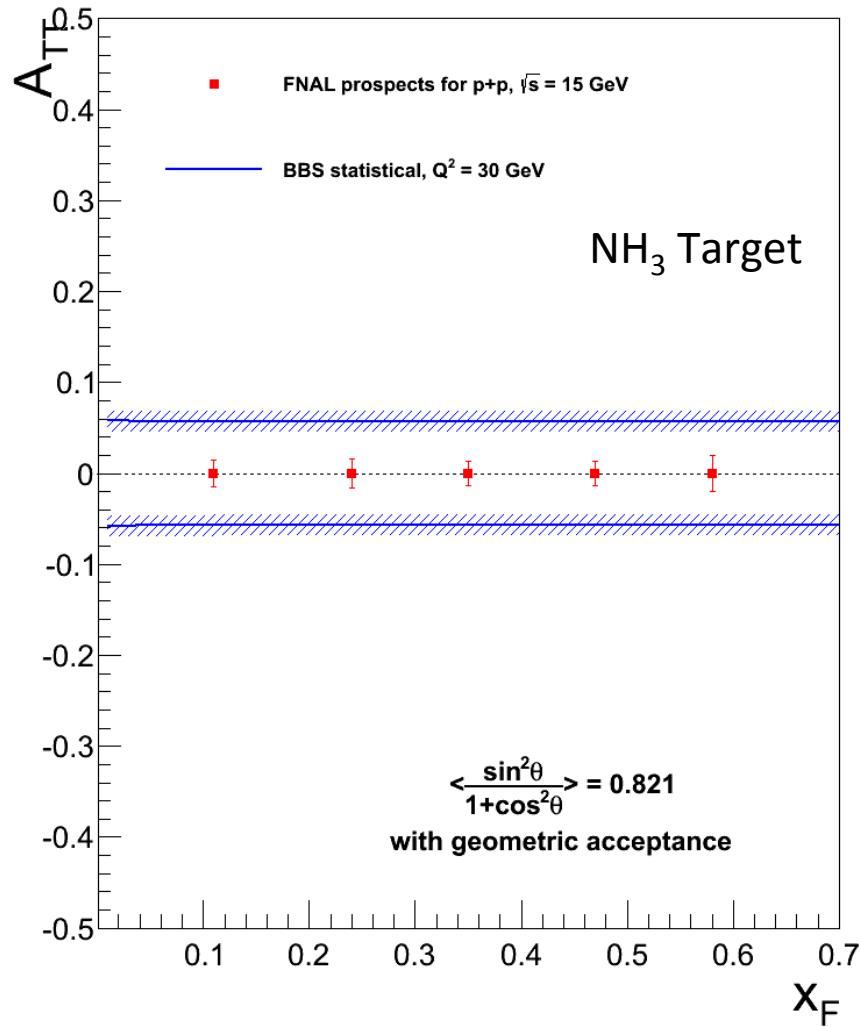
Existing Fits: Quark Transversity:

fit of semi-inclusive DIS data



From Collins asymmetry of
semi-inclusive DIS
(HERMES proton,
COMPASS deuteron), and
BELLE's correlation
asymmetry in $e^+e^- \rightarrow \pi^+\pi^-$

$A_{\pi\pi}$ FNAL "prospected data" vs. theory predictions



My Questions:

**(Reliable) Predictions
or upper bounds for :**

- **Sea quark polarization ?**
- **Sea quark transversity ?**
- **Sea quark Sivers distribution ?**

Summary-I

Polarized Target Drell-Yan at FNAL

E-1039 Polarized target SSA, access sea quark Sivers.

- **Sea Quark Angular Momentum (A_{UT})**

In the future, with both polarized beam and target:

- **Sea Quark Polarization (A_{LL})**
- **Sea Quark Transversity (A_{TT})**

Outline for Wednesday

I will discuss experimental results, physics impacts, interpretations, and the connections of the observed single spin asymmetry (SSA) phenomena in:

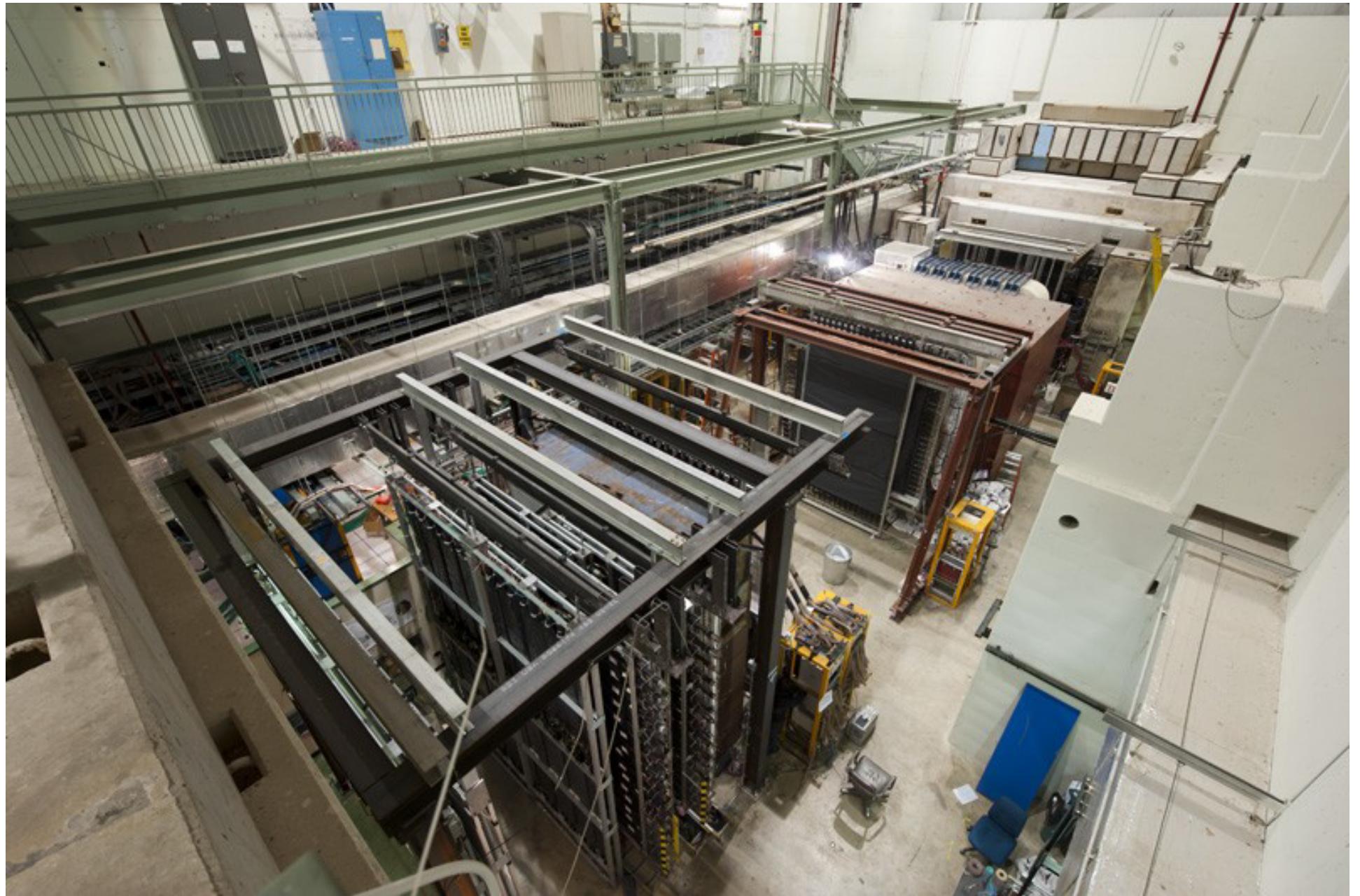
- Inclusive hadron SSA observed in proton-proton collision at Fermilab and RHIC.
- Target SSA in semi-inclusive deep inelastic scattering (SIDIS).
- **New Jefferson Lab results of polarized target SSA in inclusive hadron production $e+N \rightarrow h+X$ (arXiv_1311:1866)**

I will also discuss on-going and future experimental efforts, including :

- Polarized target Drell-Yan experiments at Fermilab (E-1039).
- **Forward jet production asymmetry in $p+p$ with the upgraded PHENIX experiment at RHIC.**

I will raise my own questions to PKU colleagues during the seminar for discussions.

Backup Slides



12/23/13

SSA discussions at PKU